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PORTAL CIRCULATION IN PORTAL HYPERTENSION

by

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Direct measurement of the portal pressure in human beings was first described by THOMPSON et coll. (1937). They found the pressure raised in chronic portal obstruction. Such obstruction can result in dilation of the veins between the portal system and the caval system, sometimes with consequent esophageal varices, caput Medusae or hemorrhoids. Splenomegaly is also common. The cause of the enlargement of the spleen is not properly understood; many authors, such as WARTHIN (1910) and EPPINGER (1920), consider it secondary to stasis. This clinical picture is known as portal hypertension (GILBERT and CARNOT 1902, MC INDOE 1928).

Velocity of flow in the portal system has been measured by non-radiologic methods, the time taken for a suitable substance (ether, acethylene, or dye) to travel a known distance. The velocity of flow in the portal system in portal hypertension has been reported as abnormally slow by NEWMAN and COHEN (1949), who measured the rectum-lung time (ether), by HENNING et coll. (1950), who measured the duodenum-lung time (acethylene), and by HUNT (1954), who injected radioactive isotopes into a mesenteric vein in association with laparotomy.

Lieno-portal venography has proved useful in the evaluation of circulatory disturbances in portal obstruction. The purpose of the present investigation was to study different aspects of these disturbances as judged by changes in the collateral circulation, the velocity of flow, and the width of the portal vein and the splenic vein as seen in lieno-portal venograms of subjects with and without portal hypertension.

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Earlier investigations of the portal circulation by lieno-portal venography

A filling of the collaterals in lieno-portal venography was first described by DREYER and BUDTZ-OLSEN (1952). This they observed in a patient in whom no filling was obtained of the portal vein. ABEATICI et coll. (1952), who also obtained a filling of the collaterals in patients with obstruction of the splenic or portal vein, interpreted this filling as a sign of reverse direction of flow in the collaterals. SOTGIU et coll. (1952) obtained a filling of the collaterals and of a widened portal vein in one case and suggested that such appearances might indicate portal hypertension. In 1953 MILNES WALKER et coll., COOPER et coll., and JAHNKE et coll. emphasized the usefulness of lieno-portal venography for evaluating the function of a porta-caval shunt. They found that if an anastomosis is functioning adequately, the contrast medium will pass through it into the inferior caval vein without the filling of any collaterals.

Since then a filling of the collaterals has often been stressed as an important sign of portal hypertension (CACCIARI and FRASSINETI, KONAR and SEN GUPTA 1953, GVOZDANOVIĆ and HAUPTMANN, LEBON et coll., SCHOLZ et coll. 1954, BERGSTRAND and EKMAN, FIGLEY et coll., LEGER 1955).

ATKINSON et coll. (1955) described 35 patients, mostly with cirrhosis. They found a filling of the collaterals to be a definite, though not regular, sign of increased portal pressure (intrasplenic pressure of more than 15 mm Hg). They also claimed lieno-portal venography to be the most reliable method available for the diagnosis of esophageal varices.

The velocity of the portal flow was first assessed by lieno-portal venography by ABEATICI et coll. (1952). By means of serial films of 13 patients they judged the time necessary for the contrast medium to fill and to leave different portions of the portal system. In 12 patients — mostly with tumours involving the portal system — the rate of circulation was found to be slower than in their one control.

In a preliminary report (BERGSTRAND and EKMAN 1955) we described the flow of the contrast medium as abnormally slow in liver cirrhosis with portal hypertension. The rate of flow of the contrast medium, as judged by films taken with an automatic film changer, was measured from the end of the injection of contrast medium until the medium had left the intrahepatic portal branches. FIGLEY et coll. (1955) independently used a similar method.

In 16 patients ATKINSON et coll. (1955) judged the velocity of flow by the interval between the beginning of the injection and the filling of the small intrahepatic portal branches. They found this interval to be longer when a filling was obtained of the collaterals. GVOZDANOVIĆ and HAUPTMANN (1955) estimated the velocity of flow by measuring the distance the contrast medium advanced between two consecutive films taken at a short interval (0.25 to 0.5 sec). They found the circulation to be slower in 8 cases with filling of collaterals than in 6 controls (1956).

The widths of the splenic vein and the portal vein in patients with splenomegaly were measured by GVOZDANOVIĆ and HAUPTMANN (1955). They gave 1.5 and 1.7 cm, respectively, for 7 patients with hereditary sphaerocytosis, as against 1.8 and 2.1 cm for 11 patients with liver cirrhosis. On the basis of a small number of cases KONAR and SEN GUPTA (1953) and FIGLEY et coll. (1955) pointed out the tendency to vascular dilation in portal hypertension.

DOEHNER et coll. (1955 and 1956) measured the width of the vessels in the portal system by means of portal venography at autopsy. In the presence of liver cirrhosis they found the splenic vein to be dilated, but not the portal vein.

Authors' investigations

Lieno-portal venography. The technique employed was essentially that described earlier (BERGSTRAND and EKMAN 1955). Thus with the guidance of a preliminary roentgenogram and with the patient in the supine position the spleen was punctured under local anesthesia. In 90 of the 115 technically successful examinations the spleen was punctured while the subject was holding a deep breath.

In the remaining 25 examinations the spleen was punctured with the patient in the resting respiratory state. Shallow breathing was allowed during the examination. In these cases the spleen was punctured with a cannula containing a mandrin. Not until the examiner had convinced himself that the tip of the cannula was in the pulp, as demonstrated by the flow of blood from the free end of the cannula on withdrawal of the mandrin, was contrast medium injected. We now use this latter method routinely in the absence of splenomegaly.

In most of the examinations 30 ml Triurol 50 % (sodium acetrizoate: specific gravity 1.3; viscosity at 37° C 2.1 centipoise) was injected at the rate of 6 to 7.5 ml/sec. In 106 examinations the passage of contrast medium from the spleen was followed by serial films taken with the aid of an automatic film changer. In the remaining 9 examinations the films were changed by hand and 3 films taken within 6 to 8 seconds.

Exposure data: F. F. D. 95 to 100 cm, 500 mA, 70 to 90 kV, 0.12 to 0.20 sec; cross-grid; high speed intensifying screens.

Complications: (Detailed analysis of the complications due to the examination technique and the indications of lieno-portal venography will be the subject of a future paper.) Twenty-one (21) of a total of 136 examinations failed, usually because of extra-splenic deposition of the contrast medium. In 3 patients, all with portal hypertension and severely impaired liver function, intraperitoneal bleeding was such as to indicate blood transfusion. In all 3 bleeding stopped spontaneously.

Assessment of the collateral circulation. A filling of vessels from the splenic vein and/or the portal vein was taken as a sign of collateral circulation. A filling of small vessels from the hilum of the spleen was, however, not considered pathologic.

The size of the collateral circulation in patients with liver cirrhosis was judged by the width and number of the collaterals demonstrated.

Assessment of the velocity of portal flow. In 63 of the examinations carried out with an automatic film changer the contrast medium flowed unobstructed through the splenic and portal veins to the liver. In these the velocity of flow in the splenic vein and portal vein was estimated in 4 different ways (Fig. 1).

1. Measurement of the distance that the head of the contrast medium had advanced between 2 consecutive exposures at a known interval was

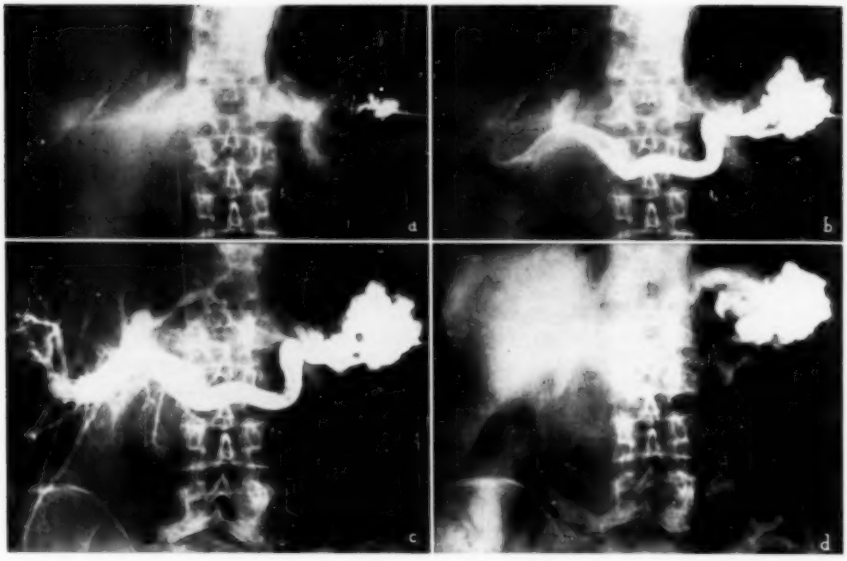


Fig. 1. *Control.* No filling of collaterals a) at beginning of injection; b) 1 sec after beginning of injection: contrast medium has reached bifurcation of the portal vein at hilum of liver; c) 4 sec after beginning of injection: contrast medium has filled the intra-hepatic portal branches; d) 5 sec after end of injection: contrast medium has left the intra-hepatic portal branches and accumulated evenly in the liver parenchyma.

assessed in cm/sec. If the contrast medium had passed the liver hilum by the time of the second exposure, no attempts were made to assess the velocity of flow. In the analysis of the results we always used only the largest distance recorded between two consecutive exposures. Like GVOZDANOVIĆ and HAUPTMANN (1955) we did this in order to diminish the source of error due to the tortuousness of the vessels in planes other than that of the film. In about one third of the cases the outline of the head of the column of contrast medium was not sharp enough to permit estimation with an accuracy closer than $\pm$ 2 cm.

2. The interval between the beginning of the injection of contrast medium until demonstration of the bifurcation of the portal trunk in the liver hilum was called *the spleen-hilum time* (Fig. 1 b). Measurement of the interval was most accurate in those 30 cases in which the commencement of the injection was 'caught' by one of the serial films. In the remainder the first film was taken 1 to 2 seconds after the injection had been started. This interval was measured with a stop-watch, which was found satisfactory. Determination of the moment when the contrast medium reached the bifurcation of the portal vein offered no difficulties.

3. The interval between the moment the injection of the contrast medium was started and the moment the contrast medium filled the smallest observable intrahepatic portal branches in the right liver lobe was called *the spleen-liver time* (Fig. 1 c). This lobe was selected because the veins there are filled both quicker and better than in the left lobe.

4. The interval between the end of the injection until the moment the intrahepatic portal branches were no longer discernible was called *the emptying time of the portal branches* (Fig. 1 d). At the end of the injection the contrast medium in the splenic vein was almost immediately diluted with blood, for which reason this moment could be determined with exactitude. As in the determination of the spleen-liver time, determination of the emptying of the portal branches was assessed only on data obtained for the right liver lobe. Experience showed that satisfactory assessment of the emptying time of the portal branches required serial films at the rate of 1 film/sec for at least 6 seconds after the end of the injection. This requirement was satisfied in 47 of the 63 examinations. In the remaining 16 cases, films were taken at the rate of 1 every 2 to 3 sec.

The concentration of the contrast medium in the liver parenchyma was judged by comparison with films in which the contrast medium had not yet reached the liver.

As pointed out earlier (BERGSTRAND and EKMAN 1955), the hepatic veins are usually filled with contrast medium within 15 to 20 seconds of the end of the injection. In 42 of the 63 examinations this phase was followed with films taken every third to fifth second. In order to study the flow of the contrast medium through the entire portal system we now take films every second for 13 seconds after the beginning of the injection and every third second for the following 20 seconds.

The widths of the splenic vein and the portal vein as seen in the lieno-portal venogram were taken as the calibers of these vessels. Owing to the tortuosity of the splenic vein and the rapidity with which the contrast medium is injected, it may be assumed that intermixture is adequate and that the widths of the veins as seen in the lieno-portal venogram are representative of their calibers. The diameter of the splenic vein was measured hepato-proximally where it was usually of uniform width, while the portal vein was measured hepato-distally, where it was widest. No correction was made for variation in vessel—film distance with body-build.

Determination of the pressure in the portal vein. In 40 patients the portal pressure was measured at operation, during which a portal tributary was catheterized and the pressure recorded with a saline manometer. The mid-axillary line was taken as the base line. With this method the upper normal limit is 21 cm H_2O (EKMAN — to be published). In 13 patients the portal pressure was determined by measurement of intrasplenic pres-

sure by the following technique. With the patient in the supine position, and after cutaneous anesthetization over the mid-axillary line at the level of the 9th—10th intercostal space, a cannula was introduced into the pulp of the spleen. Its mandrin was then withdrawn and the cannula connected to a saline manometer. With this method values of more than 25 cm H_2O were found only in patients with portal hypertension verified in some other way (EKMAN — to be published).

Demonstration of esophageal varices. Of the 88 patients, 79 were examined roentgenographically for esophageal varices. The technique employed was essentially that recommended by WOLF (1928), SCHATZKI (1933 and 1940), and OPPENHEIMER (1937). The examination was carried out under fluoroscopic control with the patient on the horizontal examination table. The examination included films taken while the patient was holding a deep breath because then the lower part of the esophagus is not masked. The exposure times were kept short (0.05 to 0.08 sec). Proper compression of the chest proved important for obtaining satisfactory roentgenograms. In a large number of cases films were also taken with the subject straining. Straining was never found to increase the size of the varices. Varices extending above the middle of the esophagus were said to be large; those extending above the lower third of the esophagus, as medium-sized; those involving only the lower third, as small.

Assessment of the size of the spleen. Assessment of the size of the spleen by palpation is unsatisfactory. In 83 of the 88 patients the size of the spleen was therefore measured roentgenographically. The patient was examined in the fasting state with the bowel properly cleared. With the patient supine films were taken in deep inspiration. Even if the spleen is of normal size its lower pole will not be masked by the ventral parts of the ribs. Technical data: F. F. D. 100 cm, 60 to 70 kV, 200 to 300 mAs; Bucky grid; the tube was centered on the spleen. With this technique the lower pole can be demonstrated but not the cranial and medial outline. The distance, as measured in the films, between the level of the most cranial part of the diaphragmatic arch and the lower pole of the spleen was therefore taken as a measure of the size of the spleen and is referred to hereinafter as *spleen length*. Owing to individual differences between the position of the spleen in relation to the diaphragmatic arch, in the direction of the axis in the sagittal and frontal planes, and differences between spleen—film distance with variations in body-build, it is hardly possible to obtain a more accurate roentgenographic measurement of the size of the spleen in conventional films. However, on examination of a given patient on different occasions for any further enlargement of the spleen, the effect of this individual variation in the topography of the organ will be negligible.

In a control series of 50 adults (23 males and 27 females) without known symptoms or signs of liver or spleen disease the spleen length varied between 8 and 19 cm (mean 12.4 ± 2.2 cm). (Analysis by the χ^2 method did not argue against the control material being of normal distribution.) On the basis of these controls it may be assumed with 97 per cent probability that a spleen length of more than 16 cm should be regarded as pathologic.

Material

The material consisted of 115 successful lieno-portal examinations carried out from 17 November 1953 to 10 April 1956 on 88 patients.

The patients are classified below (5 groups) according to final diagnoses. The diagnoses were based on thorough clinical examinations and roentgenology. In 70 cases the diagnoses were also verified at laparatomy, by biopsy or by necropsy.

1. *Controls.* The controls consisted of 15 patients, in whom thorough clinical examinations and roentgenology revealed no evidence of liver diseases or diseases involving the portal system (1 patient was examined on 2 occasions).

2. *Patients with expansive processes.* This group consisted of 18 patients. Six (6) had an expansive growth adjacent or involving splenic vein or the portal trunk with consequent extrahepatic portal obstruction. In 10 the process was intrahepatic, and in 2 a tumour occluded the inferior caval vein above its union with the hepatic veins.

3. *Patients with liver cirrhosis.* This group consisted of 38 patients examined on 63 occasions. (In one patient cirrhosis with portal hypertension developed between two examinations for which reason this patient is regarded as two cases, one in Group 5 and one in Group 3); 25 of the examinations were postoperative to assess the function of a porta-caval shunt. In 31 of these 38 cases the clinical diagnosis was verified by biopsy.

4. *Patients with extrahepatic thrombosis.* Nine (9) patients showed signs of long standing thrombosis of the splenic vein or the portal trunk without signs of tumour. One (1) of these patients was examined twice.

5. *Miscellaneous diseases.* This group comprised 8 patients with diseases possibly capable of involving the portal circulation (congenital stricture of the portal vein in 1, Cruveilhier-Baumgarten's syndrome in 2, cardiac decompensation in 1, and jaundice without signs of liver cirrhosis in 4).

The usefulness of lieno-portal venography in the diagnosis of portal hypertension was assessed on the basis of a comparison between the findings in patients with and without known portal hypertension.

A. *Patients without portal hypertension.* Patients without signs of disease known to be capable of influencing the portal circulation and patients in whom the portal pressure was found to be normal were assigned to this group.

B. *Patients with portal hypertension.* This group consisted of patients with typical symptoms and signs of portal hypertension — bleeding from the upper alimentary tract, splenomegaly and, in some cases, ascites. This group included not only patients in whom the portal pressure was found to be increased, but also those with esophageal varices, even if the portal pressure had not been measured.

On the basis of pressure measurements and examinations of the esophagus as well as the clinical picture, 16 out of the 88 patients were assigned to Group A — patients with normal circulation in the portal system — and 54 to Group B — patients with portal hypertension. Owing to incomplete examinations of the portal circulation, the remaining 18 cases were not assigned to either of these 2 groups.

Of the 16 subjects belonging to Group A, 15 were from the controls. The remaining case in the group was seen in a man, aged 55, from the miscellaneous group with a long history of heart disease. At the time of the examination he showed no signs of cardiac decompensation. The intrasplenic pressure was 18 cm H_2O. These 16 subjects were examined with lienoportal venography, one of them twice.

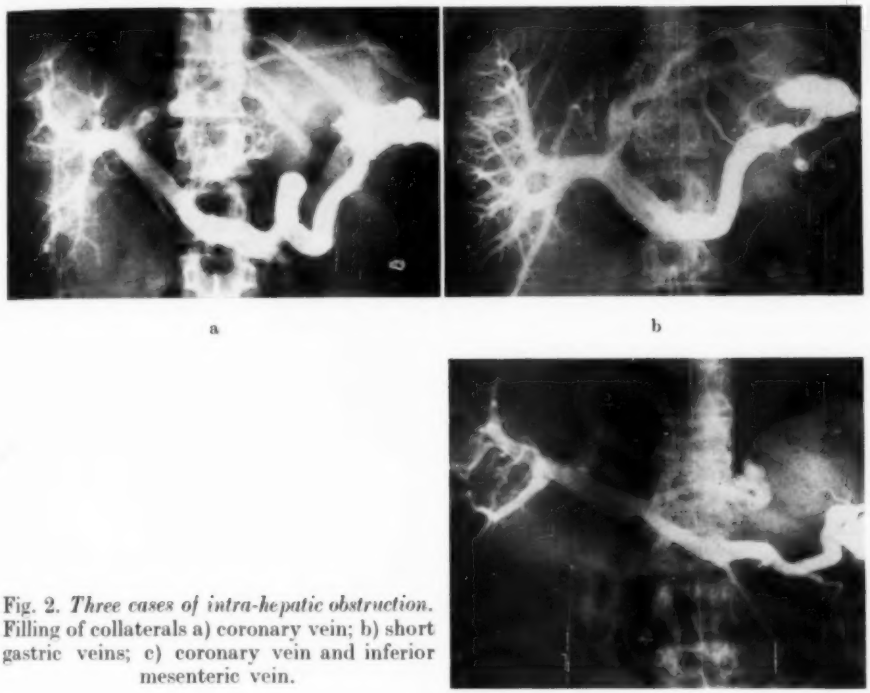
Of the 54 patients belonging to Group B, 6 were in the group with expansive processes, 36 in the group with cirrhosis, 9 in the group with extrahepatic thrombosis and 3 in the miscellaneous group. All of these patients were examined with lieno-portal venography, one of them twice.

Results

Collaterals. The results of the 90 lieno-portal venographies carried out before establishment of a porta-caval shunt are divided into 2 groups, *i. e.* with and without demonstration of collaterals.

Lieno-portal venography without filling of collaterals. Thirty-one (31) lieno-portal venographies including those of all controls showed no filling of collaterals. The contrast medium regularly passed unobstructed via the splenic vein and portal vein and the intrahepatic portal branches through the liver (Fig. 1). In the controls a marked accumulation of contrast medium was observed in the liver parenchyma within 4 to 5 seconds of the end of injection, and after a further 3 to 5 seconds a filling of the hepatic veins was obtained in 14 of 19 assessable patients.

Lieno-portal venography with filling of the collaterals. (The morphology of the collaterals in portal obstruction of varying origin and of the intrahepatic portal branches will be described in greater detail in a future paper.) A filling was obtained of the collaterals in 59 lieno-portal venographies. In 21 this was due to obstruction of the flow of contrast medium to the liver, an obstruction located in the splenic vein or the portal vein and thereby showing signs of extrahepatic obstruction. In the remaining 38 examinations in which a filling was obtained of the collaterals the contrast medium passed unobstructed to the liver. In these the intrahepatic portal branches usually showed a varying degree of obstruction or displacement according to the nature of the pathologic process. In several cases, however, they appeared normal. In the 2 cases with post-hepatic obstruction the pattern of the portal branches was normal. In the presence of liver cirrhosis the accumulation of contrast medium in the liver parenchyma often appeared mottled. In the presence of a collateral circulation the accumulation of contrast medium was markedly less than in the controls. This decreased accumulation was likewise striking in 4 of 9 patients with cirrhosis with only a small collateral circulation. In 1 of these portal venography was performed post mortem. In contrast to what is normally



a b c

Fig. 2. *Three cases of intra-hepatic obstruction.* Filling of collaterals a) coronary vein; b) short gastric veins; c) coronary vein and inferior mesenteric vein.

seen (DOEHNER et coll. 1956), the contrast medium flowed over into the hepatic veins. In another patient of the group the hepatic veins began to appear already 3 seconds after the end of the injection as against normally 8 to 10 seconds. The hepatic veins were outlined only in 4 of 20 assessable cases of cirrhosis with demonstrable collaterals.

The collateral observed most frequently in the presence of intra- or post-hepatic obstruction was the coronary vein (Fig. 2 a). The next commonest collateral was one or more of the short gastric veins (Fig. 2 b). A filling was obtained of the inferior mesenteric vein in about one third of these cases (Fig. 2 c). In no instance was a filling obtained of the superior mesenteric vein.

In extrahepatic obstruction to the passage of contrast medium in the splenic vein or the portal vein the collaterals were filled distal to the obstruction. Via these collaterals the contrast medium by-passed the obstruction either directly to the caval system or to the portal system central to the obstruction. In occlusion of the splenic vein the contrast

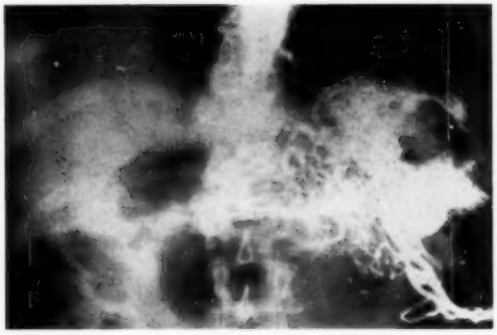
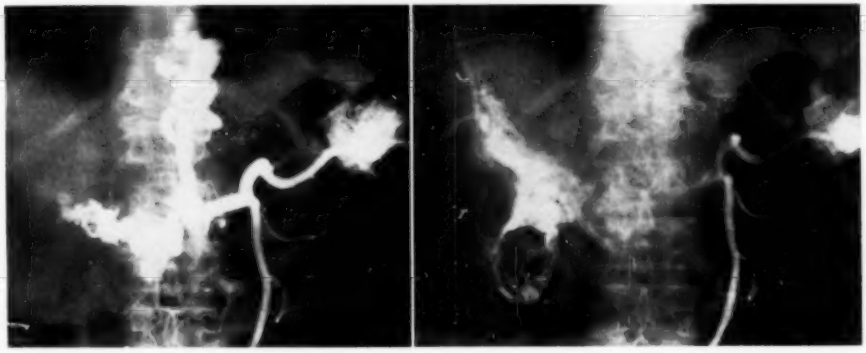


Fig. 3. *Obstruction of splenic vein.* Filling of collaterals (short gastric veins and intercostal veins). No filling of splenic vein.

medium passed via collaterals from the splenic capsule to the intercostal veins (Fig. 3). When the portal vein was occluded, a filling was obtained not only of the collaterals referred to earlier but also of veins in the hepatoduodenal ligament running towards the bed of the gallbladder (Fig. 4 a). From these veins the intrahepatic portal branches were often filled centrally to the obstruction (Fig. 4 b).

In 6 cases of portal hypertension with obstruction to the passage of contrast medium near the hilum of the spleen the contrast medium passed via collaterals to the left renal vein (Fig. 5 a and b). In 5 of these, splenorenal anastomosis was planned. At operation, however, a splenic venous thrombosis extending out to the hilum was seen in 2, and in a third, in whom the liver morphology appeared to be normal, a considerable difference was found in the pressure between the splenic vein and the portal vein suggesting an organic obstruction in the splenic vein. In the remain-



a b

Fig. 4. *Obstruction of portal vein.* a) (3 sec after beginning of injection) Filling of splenic vein and distal portion of portal vein as well as of collaterals (coronary vein, inf. mesenteric vein and veins in the hepatoduodenal ligament); b) (5 sec after end of injection). The contrast medium flows through the veins in the hepatoduodenal ligament and in the bed of the gallbladder to fill intra-hepatic portal branches central to the obstruction.

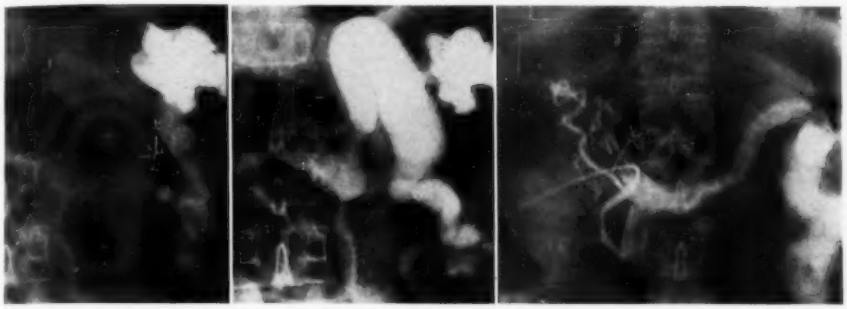


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Fig. 5. *Intra-hepatic obstruction without filling of splenic vein or portal vein.* a) (3 sec after beginning of injection) Filling of widened, tortuous collaterals from the hilum of the spleen in caudal direction. b) (5 sec after end of injection) Filling of a markedly dilated collateral vessel whence contrast medium flowed into the left renal vein and inferior caval vein. c) Portal venography during operation with injection of contrast medium via superior mesenteric vein shows a filling of splenic vein and the collateral extending towards left renal vein thus showing patency of splenic vein.

ing 2, portal venography during operation showed a passage of contrast medium between the portal vein and the collaterals to the left renal vein (Fig. 5 c). In the sixth case it was decided not to operate because the signs and the results of laboratory studies suggested severe liver damage.

Relation between the occurrence of demonstrable collaterals and portal hypertension. A filling of collaterals was obtained in all of the 54 patients with verified portal hypertension (Group B) but in none of the 16 without evidence of portal hypertension (Group A).

Relation between the occurrence of demonstrable collaterals and esophageal varices. In most cases the lieno-portal venogram showed esophageal collaterals for which reason one might expect a correlation between the size of the collateral circulation and the extent of esophageal varices, as judged by a barium swallow.

With but one exception all of the patients with demonstrable collaterals were examined roentgenologically for esophageal varices. Of 48 patients in whom a filling was obtained of collaterals because of chronic obstruction (cirrhosis, thrombosis, or malformation), esophageal varices were demonstrated in 43. In 2 of the remaining 5, varices were revealed in the stomach. Of 9 patients with collaterals due to tumour and examined for esophageal varices, small varices were seen in 4. In none of the patients without collaterals did the roentgen examination reveal varices.

Relation between the occurrence of demonstrable collaterals and spleen length. Spleen length could be assessed in all cases but 5. Diagram 1

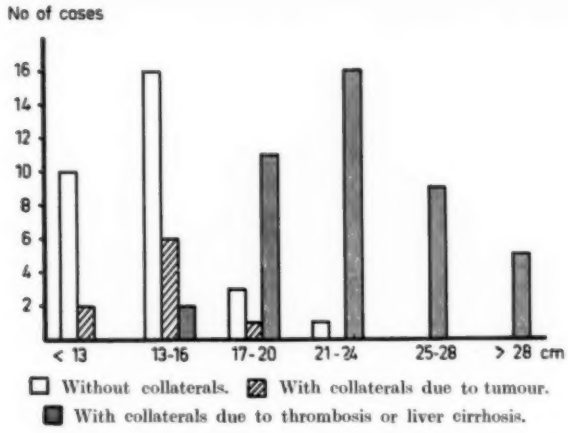

Diagram 1. Spleen length in the absence and presence of collaterals.

compares the spleen length in patients with and without collaterals; a boy, aged 2 years, was excluded. Patients with collaterals due to tumour were taken together in a separate group. Of the 30 patients without collaterals, 3 had splenomegaly because of blood disease. Of the remainders, only 1 had a spleen length of more than 16 cm (a patient with histologically verified chronic hepatitis who, 6 months later, developed portal hypertension with esophageal varices and increased pressure. Lieno-portal venography then showed a filling of collaterals). Of 9 patients with demonstrable collaterals due to tumour, the spleen length exceeded 16 cm in only 1.

Of 43 cases with a filling of the collaterals due to chronic obstruction the spleen length was 16 cm in 2 and more than 16 cm in 41.

Size of demonstrable collateral circulation compared with portal pressure, esophageal varices, and spleen length. Of 30 assessable cases of liver cirrhosis with free passage of contrast medium to the liver the collateral circulation was relatively large in 8 and relatively small in 9. No correlation was found with the portal pressure but there seemed to be some correlation with the extent of esophageal varices and the spleen length (Diagram 2).

Velocity of portal flow. The velocity of flow was assessed in 63 examinations, in 34 of which collaterals were demonstrated. The velocities of flow in the presence and absence of collaterals are compared in the table on page 14. The difference, as measured in cm/sec ($P = 0.02$ to 0.05) was not so definite as when measured by the spleen-hilum time, spleen-liver time, or emptying time of the portal branches ($P < 0.001$). The results

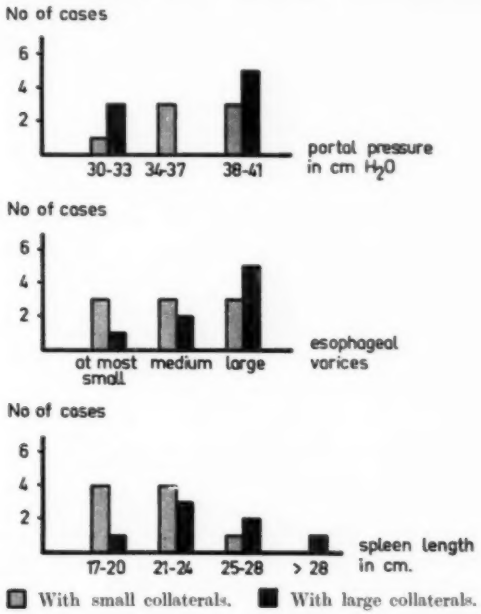

Diagram 2. Portal pressure, esophageal varices, and spleen length in patients with small and large collaterals.

obtained by each of the four methods in the presence and in the absence of collaterals were analysed by Fisher's t-test. In examinations in which the time could not be determined with an exactitude of $\pm$ 0.5 sec the statistically less favourable value was selected for subsequent analysis.

In the investigation of the velocity of flow and the width of the vessels, cases of cirrhosis belonging to Group B, *i. e.* with verified portal hypertension, were examined and the results compared with the values found in the controls — Group A. The groups were comparable with respect to age, blood pressure, and pulse rate as well as to the rate of injection of the contrast medium. Lieno-portal venography carried out in different respiratory positions and at varying intra-abdominal pressures (*e. g.* in ascites) had no apparent influence on the velocity of flow.

The velocity of flow was 15 cm/sec or more in all controls which could be judged, while in 10 cases out of 21 with portal hypertension it was 15 cm/sec or less ($P = 0.02$ to 0.05). The spleen-hilum time was at the most 2 seconds in all controls and at least 2 seconds in all patients with portal hypertension, the corresponding value for the spleen-liver time being 5 sec and for the emptying time of the portal branches likewise 5 sec (Diagram 3).

Velocity of flow in 29 examinations without filling of collaterals and in 34 with filling of collaterals

Method	Without filling of collaterals				With filling of collaterals				Results of statistic analysis
	No.	Range	Mean	Scatter	No.	Range	Mean	Scatter	P
Velocity in cm/sec	13	42—8	21.6	8.1	25	24—7	16.9	5.0	0.02—0.05
Spleen-hilum time (sec) ..	28	½—3	1.7	0.6	34	1—6	2.7	1.0	< 0.001
Spleen-liver time (sec) ...	27	3—6	4.3	0.9	33	4—10	5.7	1.1	< 0.001
Emptying time of portal branches (sec)	27	3—7	4.3	1.1	33	4—16	6.6	2.4	< 0.001

The last three methods thus showed a pronounced difference in the velocity of flow in the presence and absence of portal hypertension ($P < 0.001$). On evaluation of the rate by these 3 methods taken together the circulation in all cases in Group B (with but one exception) was always slower than in Group A. In 1 control with splenomegaly (spleen length 20 cm) the velocity of flow did not differ from that in the others. Two patients with liver cirrhosis without demonstrable collaterals had a slower circulation than any of the controls.

Of 9 cases with a relatively small collateral circulation, the emptying time of the portal branches was 4 to 5 seconds in six cases, 4 to 6 seconds in one, 6 seconds in one and 8 to 10 seconds in one. Of 7 evaluable cases with a relatively large collateral circulation, this time was 4 to 5 seconds in three, 6 to 7 seconds in three and 12 to 14 seconds in one. No correlation was found between the rate of circulation and the portal pressure in the presence of portal hypertension.

Width of the splenic and of the portal vein. The width of the splenic vein and of the portal vein could be determined in 62 of 69 examinations with free passage of contrast medium to the liver. A wide variation was noted in different cases. Diagram 4 shows the results in Group A — controls — and in cases of liver cirrhosis in Group B. In 14 assessable examinations belonging to Group A the width of the splenic vein was less than 16 mm, and of the portal vein, less than 23 mm. Of 29 assessable lieno-portal venographies in cases belonging to Group B the widths of the splenic and the portal veins exceeded the control values in 14 patients. One of these had ascites. In 11 patients both the splenic vein and the portal vein were of the same width as in the controls. Seven (7) of these 11 patients had ascites. In the remaining 4 patients of the total 29 the width of the portal vein was the same as in the controls whereas the width of the splenic vein exceeded that of the controls.

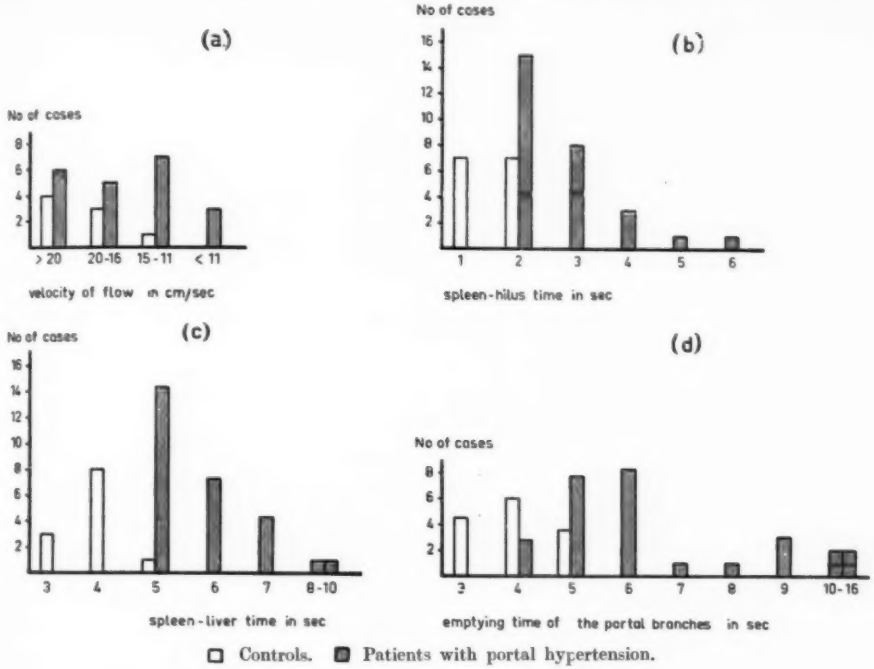

Diagram 3. Velocity of flow in the absence and presence of portal hypertension. Cases in which it was not possible to determine the values with an accuracy of ± 0.5 sec were assigned in equal proportion to columns in the possible range. In 3 cases belonging to Group B the emptying time of the portal branches was taken as 4 sec; in 2 of them because it could not be determined with an accuracy of ± 0.5 sec and in the third because the injection had been preceded by a less successful attempt.

In 2 controls with splenomegaly (spleen length 19 and 20 cm respectively) was the width of the vessels the same as in the others. In 2 patients with cirrhosis without signs of portal hypertension the vessels were of the same width as in the controls. In 7 cases with a relatively small collateral circulation without ascites the width of the portal vein was 19 to 22 mm. In 6 cases with a relatively large collateral circulation without ascites it was 22 mm in 1 case, 23 to 26 mm in 4, and 28 mm in 1 case. No correlation was found between the degree of portal hypertension and the width of the portal vein.

Of 6 cases of portal hypertension without ascites and with low velocity of the portal flow (emptying time of the portal branches more than 7 sec)

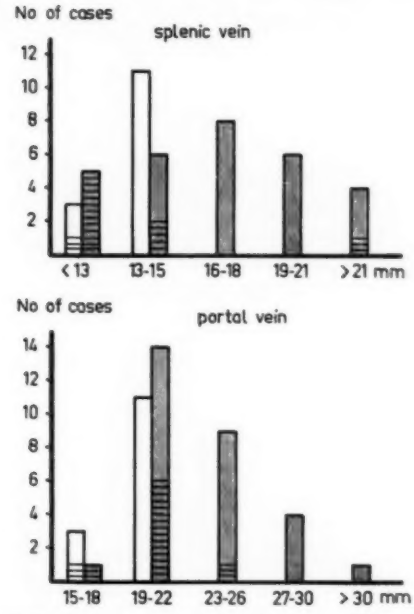

Diagram 4. Width of splenic and portal veins in the absence and presence of portal hypertension.

the width of the portal vein was 23 to 26 mm in 3 and 27 to 30 mm in 3. Of 7 corresponding cases where the emptying time of the portal branches was 4 to 5 seconds, the width of the portal vein was less than 23 mm in 5, while in the others it was 24 and 27 mm, respectively.

Discussion

Evaluation of the findings described requires knowledge of the effect of the injection of contrast medium on the hemodynamics of the portal system. DREYER (1954) found a rapid injection of as large a quantity as 20 ml saline into the spleen of the dog to have no effect on the portal pressure. In an investigation of lieno-portal venography in the dog (*in press*) we were unable to obtain a filling of collaterals by increasing the rate of injection of varying amounts of contrast medium into the spleen. Neither did such variation produce any changes in the rate of flow of the contrast medium, in the width of the vessels, or in the pressure in the

portal system. On the other hand, when the contrast medium was injected directly into the splenic vein at the same rate as by lieno-portal venography, a filling was obtained of collaterals, and changes were noted in the rate of flow of the contrast medium as well as a slight increase in the portal pressure. In dogs with collaterals, a filling of the latter was unavoidable even on very slow injection of the contrast medium.

These experiments show: 1) that in lieno-portal venography the contrast medium flows with the blood stream in the portal system, 2) that a filling of the collaterals is a sign of reverse direction of flow in these vessels.

Filling of the collaterals in all of our cases with portal hypertension is a sign of the circulatory change due to the increased pressure gradient between the portal and caval systems.

SCHOLZ et coll. (1954) and ATKINSON et coll. (1955) claimed that the size of the collateral circulation in portal hypertension is roughly proportional to the increase in portal pressure. We found no such correlation. It is possible that the duration of portal hypertension in a given case is of greater importance for the size of the collateral circulation than the degree of portal pressure. The correlation between the size of the collateral circulation and the extent of esophageal varices was not found to be so clear as expected.

This is probably due to the fact that the collateral circulation does not always involve the submucous plexus in the esophagus, and secondly it might be possible that a satisfactory filling is not always obtained of all the collaterals. Like ATKINSON et coll. we always found a filling of collaterals in the presence of esophageal varices. Neither was any definite correlation found between spleen length and size of the collateral circulation. In the evaluation of the lieno-portal venogram the spleen length usually suggested whether the obstruction was recent, *i. e.* due to tumour, or long-standing (Diagram 1).

The decreased accumulation of contrast medium in the liver parenchyma in cirrhosis with portal hypertension can be explained by a certain amount of contrast medium by-passing the liver via collaterals or by its probable passage via the intrahepatic veno-venous communications. Such veno-venous anastomoses have been demonstrated by the corrosion technique by MC INDOE (1928) and POPPER et coll. (1952) inter alios. Our case with a rapid appearance of the hepatic veins in the lieno-portal venogram and the one in which the contrast medium passed over into the hepatic veins during post-mortem portal venography support this assumption. Using portal venography DANIEL et coll. (1952) observed an abnormally rapid flow of contrast medium through the liver and decreased accumulation of contrast medium in the liver parenchyma of rats with experimental cirrhosis.

The poorer filling of the portal branches in the more ventrally located left liver lobe may be explained by the specific gravity of the contrast medium being higher than that of the blood. This assumption is based on a personal observation (*in press*) that the filling of these branches in dogs examined in the supine position is likewise poor, but much better when the animals are examined in the prone position.

Some authors have carried out model experiments to determine whether it is possible to assess the velocity of the flow in the blood vessels roentgenographically. KJELLBERG (1943) found that intermixture between the blood and contrast medium was incomplete because of the higher viscosity of the blood. The higher specific gravity of the contrast medium (1.3 as against 1.05) resulted in a layer formation with the contrast medium along the floor of the vessels. The head of the contrast medium always tapered, the tip never being dense enough to be demonstrable in the roentgenogram. GREITZ (1954) found the concentration of the contrast layer in a vessel to increase with the rate of injection and inversely with the velocity of flow of the blood. GIDLUND (1956) pointed out among other things that the exposure time should be short to prevent woolliness of outline.

Determination of the true velocity of blood flow would also require a contrast medium hydrodynamically equivalent to blood, but no such contrast medium is available.

The velocities of flow in the portal vein found in the present investigation were much higher than those given by HUNT (15 to 25 cm/sec as against 9.4 cm/sec). However, HUNT carried out his investigations at laparotomy and injected the contrast medium directly into a portal tributary, for which reason the values are not strictly comparable. Our values agree with those reported by GVOZDANOVIĆ (1956) during lienoportal venography. In the present investigation in which the contrast medium was injected into the spleen a concentrated layer of contrast medium was obtained in the splenic vein and the portal vein. This permits determination of the spleen-hilum time, spleen-liver time, and the emptying time of the portal branches. In determination of the velocity of flow in cm/sec on the other hand, the cone front of the column of contrast medium was somewhat woolly (exposure time 0.12 to 0.20 sec) with the result that in about one third of the cases it was not possible to assess the velocity of flow with an accuracy closer than $\pm$ 2 cm. This may help to explain why the difference found in the velocity of flow (cm/sec) in the presence and absence of portal hypertension was not so distinct as that found for the spleen-hilum time, spleen-liver time, and emptying time of the portal branches. This difference is in reality probably still greater than that found, because the quality of the roentgenograms of the patients with liver cirrhosis was often inferior to that in the control group (owing to *e. g.* ascites). This probably implies that the times noted were shorter than they would have been if the roentgenograms had been of better quality with the fine intrahepatic vessels well shown.

Whether the two groups differed from one another in the concentration of the contrast medium because of differences in width of the vessels or in velocity of flow cannot be decided. But such differences if any would hardly influence the results. The difference found — a lower velocity in the presence of portal hypertension — was statistically significant and consistent with findings arrived at by the indirect determination of the velocity of flow in the portal system (NEWMAN and COHEN 1949, HENNING et coll. 1950, HUNT 1954).

Assessment of the diameter of the splenic vein or portal vein by measurement of its width in the roentgenogram requires a filling of at least half the lumen. Such a filling is obtained more readily in tortuous vessels and when the contrast medium is injected rapidly (KJELLBERG 1943, GREITZ 1954). These requirements were fulfilled in the present investigation. No appreciable difference was found between the values obtained in one and the same patient examined on different occasions; the width of a vessel, as seen in the roentgenogram, was therefore presumably a good measure of its caliber.

In our material the increase in width of the splenic vein and the portal vein in portal hypertension was greater than that given by GVOZDANOVIĆ and HAUPTMANN (1955). In their material, however, all the controls had splenomegaly as against only 2 of our 13. This might explain the difference between their results and ours, if the width of the splenic vein and that of the portal vein should vary with the degree of splenomegaly. The increase in the widths of the splenic and portal veins in portal hypertension appears to be smaller in the presence of ascites.

Conclusions

The investigation was based on 115 lieno-portal venographies most of which were performed with an automatic film changer and by standardized technique. This is probably the largest material of its kind on record.

The following conclusions are founded on a comparison between 54 patients with verified portal hypertension and 16 controls, most without splenomegaly. A search of the literature failed to reveal any earlier reports of such a comparison.

A filling of the collaterals is regularly obtained in the presence of portal hypertension but never in its absence. ATKINSON et coll. (1955) found a collateral circulation to be a definite, though not regular, sign of increased portal pressure.

The velocity of flow in the portal circulation is practically always lower in the presence of portal hypertension. This conclusion is based on determinations made by 3 different methods. ATKINSON et coll.

(1955), who measured the 'spleen-liver time', and GVOZDANOVIĆ (1956), who determined the velocity of flow in cm/sec, found the velocity of flow to be slower in the presence of collaterals.

The widths of the splenic vein and portal vein are often increased in the presence of portal hypertension. On the basis of a small number of cases KONAR and SEN GUPTA (1953) and FIGLEY et coll. (1955) also pointed out the tendency to vascular dilation in portal hypertension.

In liver cirrhosis the accumulation of contrast medium in the liver parenchyma was less dense and the hepatic veins were less frequently demonstrable than in controls.

It appears that the contrast medium always followed the direction of flow of the blood stream and that the velocity of flow of contrast medium can be accepted as a measure of the true flow. This assumption is receiving attention in an experimental investigation in dogs (to be published).

SUMMARY

A total of 115 successful examinations by means of lieno-portal venography are analysed and discussed. A filling of the collaterals was always obtained in the presence of portal hypertension but never when this was absent. In portal hypertension the velocity of flow in the portal circulation was found to be lower and the widths of the splenic vein and portal vein to be increased. The method used in the present investigation is accurate enough for the clinical diagnosis of portal hypertension.

ZUSAMMENFASSUNG

Insgesamt 115 erfolgreiche Untersuchungen mit der lienoportalen Venographie werden analysiert und besprochen. Ausfüllung der Kollateralen wurde bei Anwesenheit portalen Hochdruckes immer erreicht, jedoch niemals, wenn dieser fehlte. Bei Portahypertension war die portale Zirkulationsgeschwindigkeit verlangsamt und die Weite der V. lienalis und der V. portae hatte zugenommen. Die in der vorliegenden Untersuchung angewendete Methode ist für die klinische Diagnose des portalen Hochdruckes ausreichend genau.

RÉSUMÉ

Les auteurs étudient et analysent un groupe de 115 examens spléno-portographiques réussis. Ils ont toujours obtenu l'opacification des collatérales quand il y avait une hypertension portale, mais jamais quand il n'y en avait pas. En cas d'hypertension portale la circulation était moins rapide que d'ordinaire et le calibre des veines était augmenté. La méthode utilisée dans ces recherches est suffisamment précise pour le diagnostic clinique d'hypertension portale.

REFERENCES

ABEATICI, S., CAMPI, L. and FERRERO, R.: Sulle curve di propagazione del circolo splenoportale. Studio emodinamico del distretto lieno-epatico mediante portografia seriata. Minerva Chir. 7 (1952), 886.

ATKINSON, M., BARNETT, E., SHERLOCK, S. and STEINER, R. E.: The clinical investigation of the portal circulation with special reference to portal venography. Quart. J. Med. 24 (1955), 77.

BERGSTRAND, I. and EKMAN, C.-A.: Percutaneous lieno-portal venography. Acta radiol. 43 (1955), 377.

— Perkutan splenoportografi (Swedish). Nord. Med. 54 (1955), 1563.

— Några röntgenologiska synpunkter på portasystemets hämodynamik (Swedish). Nord. Med. 56 (1956), 1184.

CACCIARI, C. and FRASSINETI, A.: Evaluation of the radiologic visualization of the splenoportal vein. Arch. ital. mal. app. diger. 19 (1953), 353.

COOPER, D. R., BROWN, R. C., STONE, C. H. and FERGUSON, L. K.: Splenoportography. Ann. Surg. 138 (1953), 582.

DANIEL, P. M., PRICHARD, M. L. and REYNELL, P. C.: The portal circulation in experimental cirrhosis of the liver. J. Path. & Bact. 64 (1952), 53.

DOEHNER, G. A., RUZICKA, F. F., HOFFMAN, G. and ROUSSELOT, L. M.: The portal venous system: Its roentgen anatomy. Radiology 64 (1955), 675.

DOEHNER, G. A., RUZICKA, Jr., F. F., ROUSSELOT, L. M. and HOFFMAN, G.: The portal venous system: On its pathological roentgen anatomy. Radiology 66 (1956), 206.

DREYER, B.: Splenic and portal venography. Quart. J. Exper. Physiol. 39 (1954), 93.

— and BUDTZ-OLSEN, O. E.: Splenic venography. Lancet 1952: I, p. 530.

EPPINGER, H.: Die hepatolienalen Erkrankungen. *In:* Erkrankungen der Milz. Hrsgeg. von Hirschfield, Springer. Berlin 1920.

FIGLEY, M. M., FRY, W. J., OREBAUGH, J. E. and POLLARD, H. M.: Percutaneous splenoportography. Gastroenterology 28 (1955), 153.

GIDLUND, Å.: Development of apparatus and methods for roentgen studies in haemodynamics. Acta radiol. Suppl. 130 (1956).

GILBERT, A. et CARNOT, P.: Les fonctions hépatiques. C. Naud, Paris 1902.

GREITZ, T.: The technique of ascending phlebography of the lower extremity. Acta radiol. 42 (1954), 421.

GVOZDANOVIĆ, V., HAUPTMANN, E., NAJMAN, E. and OBERHOFER, B.: Percutaneous splenic venography. Acta radiol. 40 (1953), 17.

GVOZDANOVIĆ, V. und HAUPTMANN, E.: Die perkutane lieno-portale Venographie und ihre klinische Bedeutung. Verhandl. d. deutsch. Gesellsch. f. inn. Med. 60 (1954), 644.

GVOZDANOVIĆ, V. and HAUPTMANN, E.: Further experience with percutaneous lienoportal venography. Acta radiol. 43 (1955), 177.

— An X-ray study of the lieno-portal circulation (preliminary report). Bull. Scient. Yougoslavie 2 (1955), 52.

GVOZDANOVIĆ, V.: Personal communication 1956.

HENNING, N., DEMLING, L. und KINZLMEIER, H.: Die enterale Acetylenresorption, eine Methode zur pharmakologischen Funktionsprüfung des menschlichen Pfortaderkreislaufes Deutsch. Arch. klin. Med. 197 (1950), 288.

HUNT, A. H.: An investigation of the pressures and speeds in the portal circulation. IV:e Congrès de l'Association des Sociétés Nationales Européennes et Mediterranées de Gastro-Entérologie, p. 27. Masson et Cie. Paris 1954.

JAHNKE, Jr., E. J., PALMER, E. D., SBOROV, V. M., HUGHES, C. W. and SEELEY, S. G.: An evaluation of the shunt operation for portal decompression. Surg., Gynec. & Obst. 97 (1953), 471.

KJELLBERG, S. R.: Die Mischungs- und Strömungsverhältnisse von wasserlöslichen Kontrastmitteln bei Gefäss- und Herzuntersuchungen. Acta radiol. 24 (1943), 433.
KONAR, N. R. and SEN GUPTA, A. N.: Splenic venography. Brit. Med. J. 1953, p. 810.
LEBON, J., FABREGOULE, M. et LE GO, R.: Méthodes actuelles et données nouvelles en splénoportographie. Manométrie splénique. Seriographie portale. Algérie méd. 58 (1954), 837.
LEGER, L.: Spléno-portographie. Masson et Cie., Paris 1955.
MC INDOE, A. H.: Vascular lesions of portal cirrhosis. Arch. Path. 5 (1928), 23.
MILNES WALKER, R., MIDDLEMISS, J. H. and NANSON, E. M.: Portal venography by intrasplenic injection. Brit. J. Surg. 40 (1953), 392.
NEWMAN, H. F. and COHEN, I. B.: Estimation of the portal circulation time in man. J. Lab. & Clin. Med. 34 (1949), 674.
OPPENHEIMER, A.: Esophageal varices. Am. J. Roentgenol. 38 (1937), 403.
POPPER, H., ELIAS, H. and PETTY, D. E.: Vascular pattern of the cirrhotic liver. Am. J. clin. Path. 22 (1952), 717.
SCHATZKI, R.: Reliefstudien an der normalen und krankhaft veränderten Speiseröhre, S. 79. Acta. radiol. Suppl. 18 (1933).
— Roentgen demonstration of esophageal varices. Arch. Surg. 41 (1940), 1084.
SCHOLZ, O., KOTHE, W. und AURIG, G.: Zur Anwendung der transperitonealen Splenoportographie. Zentralbl. f. Chir. 79 (1954), 1521.
SOTGIU, G., CACCIARI, C. et FRASSINETI, A.: Splénoportographie. Presse méd. 60 (1952), 1295.
THOMPSON, W. P., CAUGHEY, J. L., WHIPPLE, A. O. and ROUSSELOT, L. M.: Splenic vein pressure in congestive splenomegaly. J. clin. Investigation 16 (1937), 571.
WARTHIN, A. S.: The relation of thrombosophlebitis of the portal and splenic veins to splenic anemia and Banti's disease. Internat. Clin. 4 (1910), 189.
WOLF, G.: Die Erkennung von Ösophagus-Varizen im Röntgenbilde. Fortschr. Röntgenstr. 37 (1928), 890.

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ROENTGEN DIAGNOSIS OF PULMONARY MYCOMA

by

Herman Lodin

Considerable attention has been devoted to the diffuse pulmonary changes resulting from fungus infections. Radiologically, these are often impossible to distinguish from lesions of other aetiology. The more tumour-like, solitary fungal lesions, on the other hand, have attracted little attention. In the 25 to 30 cases described in the literature they have as a rule been termed aspergilloma. The writer's opinion, however, is that this is inapposite. Since other fungi, too, may cause such a lesion the term mycoma is proposed, in analogy with tuberculoma, the tumour-like, delimited form of tuberculosis. By mycoma is thus meant a strictly delimited, commonly solitary, tumour-like pulmonary change caused by fungal infection.

The fungi most usually met with are the *Aspergillus* varieties, but *Monilia candida* and *Streptomyces* have also been encountered. Two diverging views exist concerning the pathogenesis of the condition. One is that the fungus is purely saprophytic, and that the fungal infection is localized to existing healed or partly healed lesions of the lung, notably bronchiectasis, abscesses, cysts, etc. ('Intracavitary fungus ball', LEVIN). The other view is that the fungal infection is primary, and that the affected bronchus was previously normal. The bronchial dilatation would then be due to the primary expansion of the fungus ('L'aspergillome bronchectasiant', MONOD et coll.).

The first case to be described was published in 1938 by DÉVÉ. MONOD et coll. (1952) reviewed 9 cases, 3 of which were their own. LAGÈZE et coll. (1953) published 3 cases (1 caused by *Streptomyces albus*), and LEVIN (1956) has recently collected 27 cases, 4 of which were seen by him per-

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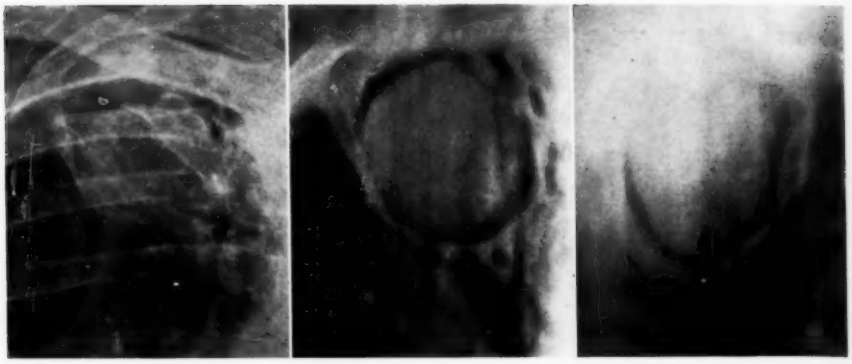


a b c

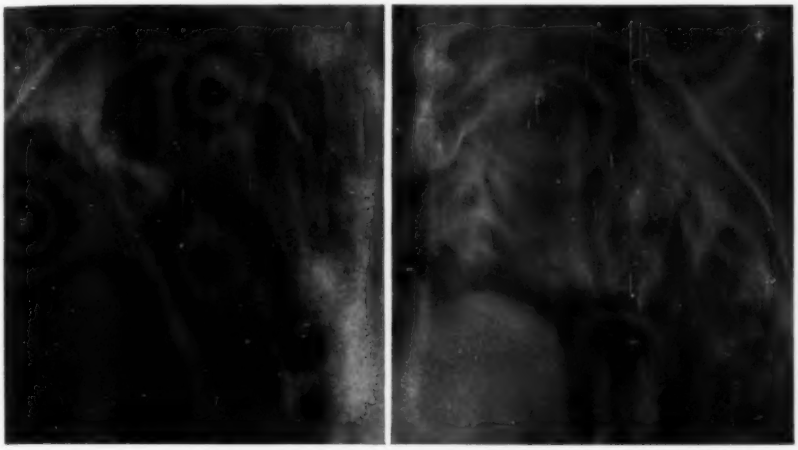
Fig. 1. Case 1. a) Conventional roentgenogram. b) and c) Frontal and lateral tomograms. Rounded, homogeneous opacity, lying in a cavity and surrounded by a layer of air. The ball is mobile (cf. the width of layer of air in a).

sonally. Of LEVIN's 27 cases, the diagnosis was confirmed by microscopy in 18; 13 of these were found to be caused by *Aspergillus*, 3 by *Monilia* and 2 by other and unspecified fungi. In most cases the only clinical sign has been haemoptysis, and none has suffered from tuberculosis.

The radiologic appearances of the lesion have been as follows. A homogeneous, more or less ball-like, mobile opacity is seen lying in a usually thin-walled cavity and connected by means of one or more bronchi to the bronchial tree. The central opacity is surrounded by a thin crescent of air and may contain calcium. The central mass is composed of matted mycelia.

We have seen 4 cases of localized, tumour-like, fungal lesions at our hospital. Of these, 3 have shown typical radiologic changes, but in the fourth the findings were uncharacteristic. Microscopic examination and culture of the sputum have repeatedly failed to reveal tuberculous infection in any of the 4 patients. Three of the cases were detected by mass roentgenography.

Case 1. A man aged 65 years. Mass roentgenography in 1945 revealed increased markings and a compact area at the right apex. Follow-up in 1950 indicated progression of the process. Conventional roentgenogram (Fig. 1 a): Round opacity at the right apex, separated from the lung tissue above by a crescent of air. Frontal and lateral tomograms (Figs. 1 b and c): Patient supine. Rounded, homogeneous opacity lying in a cavity and completely surrounded by a layer of air. The ball is mobile (cf. the thickness of the air-crescent in fig. and a), some bronchiectasis in the surrounding tissue. The patient refused operation; follow-up (1955) showed no change in the radiologic appearance.



a b

Fig. 2. Case 2. Frontal tomogram. a) Opacity at the right apex, the size of a walnut and somewhat heart-shaped, situated in a cavity and surrounded by a layer of air. b) Somewhat irregular opacity at left apex, the size of a tangerine, situated in a cavity and surrounded by air.

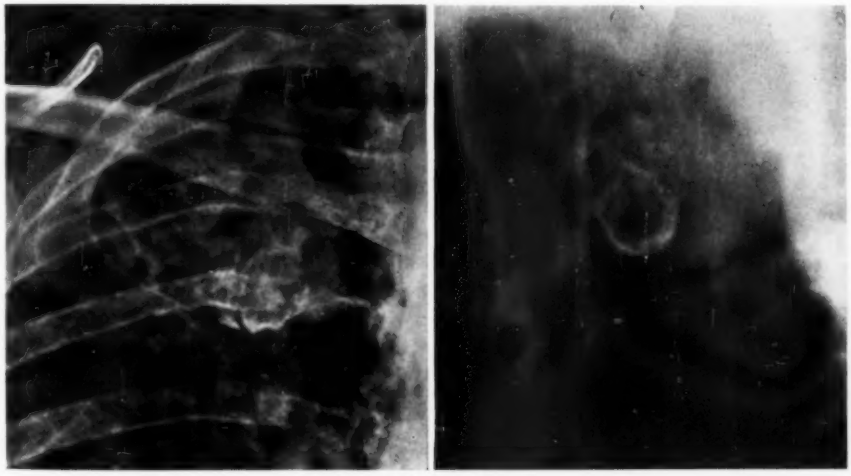


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Fig. 3. Case 3. a) Conventional roentgenogram. b) Lateral tomogram. Well-delimited, rather irregular and partly calcified opacity surrounded by a layer of air, particularly antero-superiorly, and situated in posterior segment of right upper lobe.

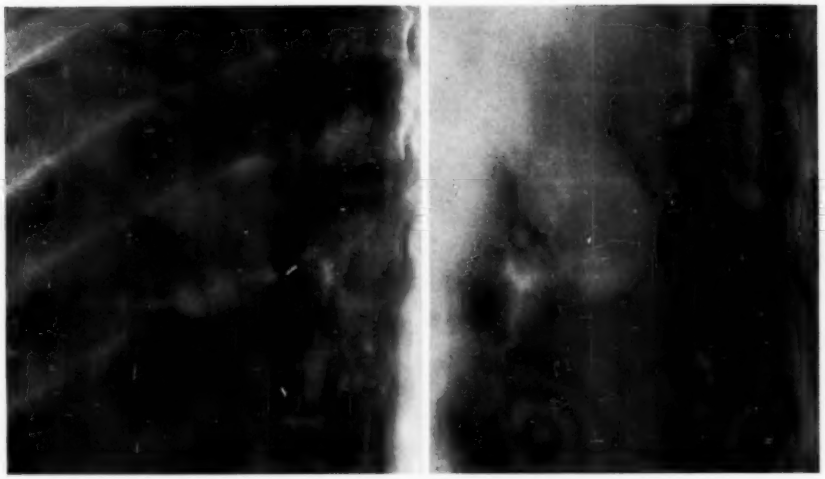
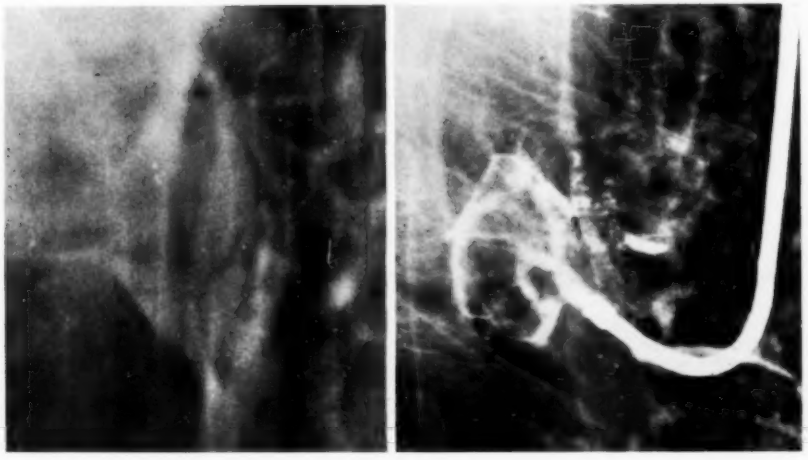


Fig. 4. Case 4. Frontal and lateral tomograms. Slightly lobulated, well-delimited, homogeneous opacity. No layer of air.



a b

Fig. 5. Lung abcess with a slough. a) Lateral tomogram. Opacity, the size of a walnut, in posterior segment of right upper lobe, separated anteriorly from a capsular wall by a layer of air. b) Bronchogram. Intracavitary body surrounded by contrast medium.

Case 2. A man aged 56. The case was detected by mass roentgenography in 1955 (a similar examination in 1945 showed normal conditions). Mantoux test (1 mg) was negative. Microscopic examination and culture of sputum and bronchial secretion revealed *Endomycetes*. Frontal tomogram. Opacity at the right apex, the size of a small walnut (Fig. 2 a), and opacity at the left apex, the size of a tangerine (Fig. 2 b). Each opacity is surrounded by air and lies in a cavity; bronchiectasis in the surrounding tissue.

Case 3. A woman aged 47. History of haemoptysis in 1940 and 1955. Conventional roentgenogram (Fig. 3 a). Irregular opacity at the right apex, containing a calcified nodule. Lateral tomogram (Fig. 3 b). A clearly delimited, partly calcified and rather irregular opacity, the size of a plum, in the posterior segment of the right upper lobe, and surrounded by a layer of air, particularly above. The whole is encapsulated. Lobectomy: a cavity containing a free, clearly delimited, partly calcified fungus mass (*Monilia candida*) was present.

Fig. 6. Tuberculoma. Lateral tomogram. Rounded focus with sickle-shaped area of rarefaction.

Case 4. A woman aged 52. The case was detected by mass roentgenography. Conventional roentgenograms revealed an atypical opacity postero-lateral to the right hilum. Frontal and lateral tomograms (Fig. 4): Lobulated, clearly delimited, homogeneous opacity. Resection of the diseased portion of the lung; abscess cavity containing *Aspergillus;* no signs of tuberculous infection or tumour.

Roentgen diagnosis. In typical cases the diagnosis is made on the presence of a mobile homogeneous opacity, situated in a cavity and surrounded by a layer of air. The patient should therefore be roentgenographed in a number of positions and the examination complemented by tomography to demonstrate the layer of air.

Differential diagnosis. Typical radiologic appearances are strongly suggestive of fungal infection. In Case 1 the diagnosis was not confirmed by microscopy or culture, but would seem to be established since the characteristic radiologic signs were present.

It will be impossible, however, to make a differential roentgen diagnosis between a mycoma, and an abscess with a slough, as the films reproduced in Fig. 5 indicate. The lateral tomogram suggests fungal infection and the bronchogram shows a rounded intracavitary body surrounded by contrast medium as by a mycoma. Operation, however, revealed an abscess with a slough.

The most important differential diagnosis is probably tuberculoma, the tumour-like form of tuberculosis (Fig. 6). The typical appearances of the two lesions are:

a) tuberculoma, a round focus containing a crescent-shaped or irregular cavity;

b) mycoma, a practically circular layer of air surrounding a more or less round focus.

Mycoma, the localized form of fungal infection, may thus appear in two forms, one showing typical and the other atypical roentgen features. Characteristic roentgen findings strongly suggest, but are not pathognomonic of fungal infection.

SUMMARY

Four cases of mycoma, a localized, strictly delimited tumour-like pulmonary lesion, are described. Of these, three had typical radiologic appearances: a more or less rounded opacity lying in a cavity and separated from the cavity-wall by a layer of air. The differential diagnosis is discussed.

ZUSAMMENFASSUNG

Vier Fälle von Mycoma, eine lokalisierte, scharf abgegrenzte tumorähnliche Lungenerkrankung, werden beschrieben. Von diesen hatten drei typische röntgenologische Merkmale, nämlich eine mehr oder weniger rundliche Verschattung welche in einem Hohlraum liegt und von dessen Wand durch eine Luftschicht getrennt ist. Die Differentialdiagnose wird besprochen.

RÉSUMÉ

L'auteur présente quatre cas de mycome, lésion pulmonaire localisée, strictement limitée, pseudo-tumorale. Trois d'entre eux avaient un aspect radiologique typique: opacité plus ou moins arrondie, située dans une cavité et séparée de la paroi de la cavité par une couche d'air. Le diagnostic différentiel est discuté.

REFERENCES

DÉVÉ, F.: Cited by MONOD et coll.

LAGÈZE, P., BÉRARD, M., GALY, P., et TOURAINE, R.: Le mégamycétome pulmonaire ou aspergillome intracavitaire. A propos de trois cas. J. franç. méd. et chir. thorac. 7 (1953), 648.

LEVIN, E. J.: Pulmonary intracavitary fungus ball. Radiology 66 (1956), 9.

MONOD, O., PESLE, G. D., et LABEGUERIE, M.: L'aspergillome bronchectasiant. J. franç. méd. et chir. thorac. 6 (1952), 229.

FROM THE ROENTGENDIAGNOSTIC DEPARTMENT (DIRECTOR: PROF. K. LINDBLOM), KAROLINSKA SJUKHUSET, STOCKHOLM, SWEDEN

A NEW CASSETTE

by

Ove Mattsson

Optimal roentgenographic effect, lightness, rigidity, and durability, are some of the qualities demanded in a modern roentgen film cassette; and it should also be as simple and fool-proof as possible in handling. Many designs have appeared but only a few satisfy the present requirements. Some of them are too heavy, and the so-called light-weight cassettes, on the other hand, are often too unstable. Other weak features are the locking systems; these often require complicated manipulation, or they are inconveniently and unsuitably arranged, *e. g.* when the mechanism is fitted externally on the backside of the cassette. Other systems have several moving parts and these gradually wear out. Frequently, the locks may be undersized so that the cassette tends to come open at a slight knock, or admit light through unintentional manipulation.

It would be of value to have a locking mechanism which does not permit to get opened accidentally. A cassette with such a device, appearing to have several other advantages, and which successfully has been tried in practice for several months, will now be described. It has a minimum of moving parts and requires the least possible manipulation for being opened or closed. The basic part of the locking mechanism is a rod — the only moving part — acted upon by a spring. The rod is provided with a number of knobs, which fit into specially shaped heels fastened to the cassette cover (Fig. 1).

To close the cassette, the cover is simply pressed downwards. The knobs of the rod then slide into locking position against the obliquely cut edges of the heels and are pushed by the spring into the notches of the heels. Then, the cassette is locked. The special shape of the heels is apparent from Fig. 1.

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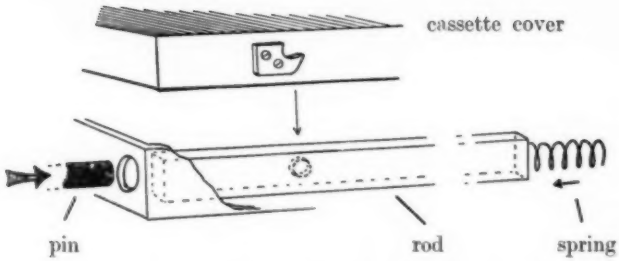

Fig. 1. Principle of locking mechanism. A rod is acted upon by a spring, which can be moved from outside by a pin. The rod has knobs which fit into heels in the cassette cover.

To open the cassette, an external pin is pushed into a hole, like a key into a key-hole, the rod is hereby made to move in longitudinal direction, the knobs are released from the heels and the cover opens. Thus, for opening the cassette the only manipulation needed is to make a pin act on the moving part of the locking system so that the cassette cover is released. The only visible part of the mechanism, on the cassette, is a small hole, through which a pin releases the lock. For this pin, different arrangements may be adopted. It may be fitted in a suitable manner to the table in the darkroom, and the cassette is then pressed against the pin. A small guiding rule suitably applied may facilitate this operation. It will probably in many instances be most practical to use a device like the one illustrated in Fig. 2.

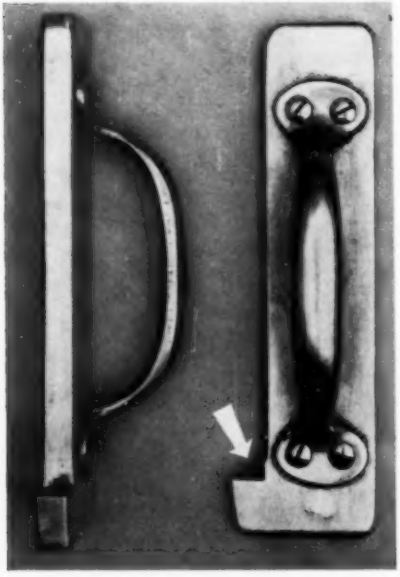

Fig. 2. Device for opening the cassette. The pin (arrow) is attached to a plate with a handle and a notch fitting the corner of the cassette.

The pin is here fastened to a plate provided with a handle. The plate has a notch to fit the corner of the cassette. The pin has been placed in such a position that it will act upon the locking mechanism through the small hole, when the device is moved along the edge of the cassette. The cassette should preferably be placed on a smooth table top. The release action is very simple and may be performed in a moment.

Fig. 3. The cassette is opened with the device shown in fig. 2. The backside of the cassette is plain and the locking mechanism has no external parts.

The cassette is made of light metal. Such a cassette with the dimensions 24 × 30 cm ($9^1/_2$ by $11^3/_4$ inches) weighs about 1,300 g, including ordinary screens. As may be seen from Fig. 3, its back surface is quite plain and smooth, except for a thin metal plate for holding labels which is mounted at the one corner of the cassette. This plate has been made to suit the labels with patient's data, which ordinarily are of a size about 7 × 10 cm, corresponding to the standard space in registering systems with stencil plates to which modern marking apparatus for roentgen films are adapted.

Thanks to the smooth and plain surfaces of the cassette it can easily be moved through the narrow spaces in automatic transport systems between dark-rooms and working places.

The interior of the cassette is conventionally arranged. The pressure pads are made of felt. In this connection it may be mentioned that the writer, after testing rubber and plastic materials, has found felt to be superior in the long run, for this purpose. The pads are so dimensioned that a very good contact between film and screens is always ensured.

The design has been worked out in close cooperation with Mr. KARL FENZ, Dr. Engineer, formerly of Georg Schönander AB., Stockholm.

SUMMARY

A new roentgen film cassette with plain and smooth surfaces and with a simple and reliable locking mechanism is described.

ZUSAMMENFASSUNG

Eine neue Röntgenfilmkassette von einfacher Formgebung und mit einem einfachen und zuverlässigen Verschluss wird beschrieben.

RÉSUMÉ

L'auteur décrit une nouvelle cassette pour film radiographique, aux lignes nettes, et qui comporte un mécanisme de fermeture simple et sûr.

FROM THE DEPARTMENT OF RADIOLOGY (DIRECTOR: PROF. F. J. HODGES) AND THE SECTION OF THORACIC SURGERY (DIRECTOR: PROF. CAMERON HAIGHT), UNIVERSITY HOSPITAL, ANN ARBOR, MICHIGAN, U. S. A.

CONTROLLED PUNCTURE AND CONTRAST INJECTION INTO THE LEFT VENTRICLE OF THE HEART

by

Björn Nordenström, Melvin Figley and *Herbert Sloan*

In the study of a number of abnormalities of the heart it would be of advantage to inject contrast material selectively into the left ventricle. Roentgenologic examination of diseased mitral and aortic valves and defects in the ventricular septum would be improved in this way. Injection of contrast material into the left ventricle could be achieved by introduction of a catheter into the ventricle in a retrograde fashion from a peripheral artery or by direct puncture of the left ventricle. Retrograde catheterization of the left ventricle of dogs was tried in some preliminary experiments. Difficulties encountered made it seem probable that direct puncture of the left ventricle was a more suitable approach.

In some earlier papers (5, 3, 4, 2, 1) it was shown that it is possible to puncture the left ventricle in dogs and human beings and to inject contrast material without frequent complications.

Sometimes, however, pneumothorax, pneumopericardium, hemopericardium, liver hemorrhage, myocardial hemorrhage, and disturbances in cardiac rhythm resulted. The most frequent disturbances of cardiac rhythm produced by puncture of the left ventricle were ventricular extrasystoles and ventricular tachycardia. When contrast material was injected through the needle, some of the material occasionally was placed in the pericardial space or in the myocardium. This accident was followed usually by severe rhythm changes which occasionally terminated in ventricular fibrillation. Although these severe complica-

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tions were infrequent they cannot be overlooked. The technique used previously, however, can be regarded as a 'blind puncture'. The needle was introduced immediately beneath the xiphoid by most investigators and then directed against the diaphragmatic surface of the heart. The danger of puncturing a coronary artery was regarded as minimal when this approach was used. The appearance of pulsating arterial blood from the needle was considered proof that the tip of the needle was in the correct position.

Although great skill may be developed in performing this procedure, a 'blind puncture' must involve more risk than a puncture carried out under some kind of control. A blind technique is not necessary for puncture of the left ventricle. By roentgenologic means, the route and depth of puncture can be determined in advance with considerable exactness. The correctness of position of the needle can also be controlled.

In order to improve the possibilities of utilizing percutaneous puncture and contrast injection in the left ventricle a technique for controlled puncture and contrast injection into the left ventricle has been developed in 25 experiments on 16 dogs.

Equipment. Puncture of the left ventricle is carried out with a modified 16 gauge needle, 15 centimeters in length. The tip of the needle is closed. Eight small holes are drilled perpendicularly to the long axis of the needle near the obturated tip. The distance between proximal and distal holes is 2 mm. The total area of the holes is somewhat greater than the cross section area of the lumen of the needle. The tip of the needle is sharp but the edges of the tip are rounded off. This cross perforated needle is thought to have the following advantages.

Fig. 1. Early stage of injection of contrast material into the left ventricle of a dog through the cross perforated needle. Atrial systole. The left ventricle is nearly completely delineated except where non-opaque blood is passing through the mitral valve.

The rounded edges of the needle tip avoid lacerating of the heart. The sharp point allows penetration of the heart without major displacement of it during the passage of the needle through the heart wall.

The obturated needle tip avoids the possibility of punching out tissue which otherwise might be introduced into the ventricle.

The multiple holes direct the contrast material into eight jets. This may diminish the possibility of local damage to the endocardium which might occur with a single forceful jet. In Fig. 1 the entrance of contrast material at an early stage of injection can be seen. The oppositely directed jets make the needle free of recoil. Lastly, the multiple jets provide better mixing of the contrast material and blood in the ventricle and may prevent interference with the function of the mitral valve.

An adjustable needle stop is employed to control the depth of puncture and to support the needle against the skin.

A pneumatic pressure syringe is used for injection of the diagnostic dose of contrast material. The beginning and completion of the injection and the roentgenographic exposures are indicated on the same recording paper as is used for electrocardiographic recordings.

The connection between the pressure syringe and the needle is a 40 centimeter long transparent, pressure-resistant plastic tubing. In the center of the tubing a large bore three-way stopcock is inserted. With this arrangement the pressure syringe and the proximal part of the connecting tubing are filled with contrast material prior to the puncture. The distal part of the tubing is employed to flush the needle with isotonic saline solution from a syringe connected to the three-way stopcock and to perform test injections into the ventricle (Fig. 2).

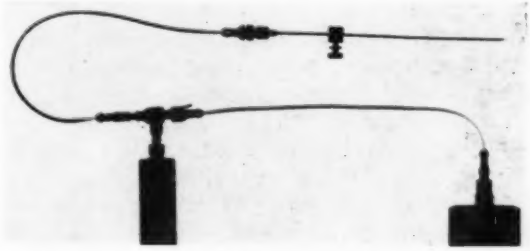

Fig. 2. Arrangement of syringes and needle. Pressure syringe on the right.

Antero-posterior and lateral roentgenograms are used for calculation of direction and depth of puncture. To obtain reference points on the films these are exposed with a centimeter scale of lead placed below the xiphoid process of the dog. Two metal protractors indicate the calculated direction of the needle. Serial filming is carried out during the injection of contrast. With the available equipment two films per second are exposed in one plane.

Urokon, 50 and 70 per cent, was used as the contrast medium in the earlier experiments. It was later replaced by a 70 per cent solution of Hypaque. (We are indebted to Winthrop-Stearns Company for supplies of Hypaque.) Sodium pentobarbital (50 mg/ml) was employed for intraperitoneal anesthesia in a dose of 0.5 ml per kilogram body weight.

Fig. 3. Intramuscular injection of contrast material. Myocardial veins and the coronary sinus are promptly opacified.

Fig. 4. Intrapericardial injection of contrast material. Coronary vessels outlined in relief.

Difficulties and errors during development of the technique. Passage of the needle through the myocardium regularly produced one or several extrasystoles, thus confirming the experience of earlier investigators. Once the needle was properly in place, additional electrocardiographic changes consisted of occasional extrasystoles, T-wave inversion and S—T segment elevation. One or two extrasystoles were regularly observed during the injection of the large dose of contrast medium. The needle remained in the left ventricle more than 30 minutes in several experiments without any additional changes in the electrocardiogram.

In the earliest experiments it was often found that the original direction, given the needle during puncture, changed in a regular way when it was left alone in the ventricle. The butt of the needle moved upward, angulating the tip into a more posterior part of the ventricle. It may be that displacement of the very mobile dog's heart can explain this discrepancy between intended and final position. In order to overcome a positional change during puncture it seemed reasonable to advance the needle rapidly through the heart wall.

In some experiments the needle was not attached to the connecting tubes during the puncture. Air was seen in the pleural and pericardial spaces following the puncture and, in one instance, a small air bubble was seen in the left ventricle.

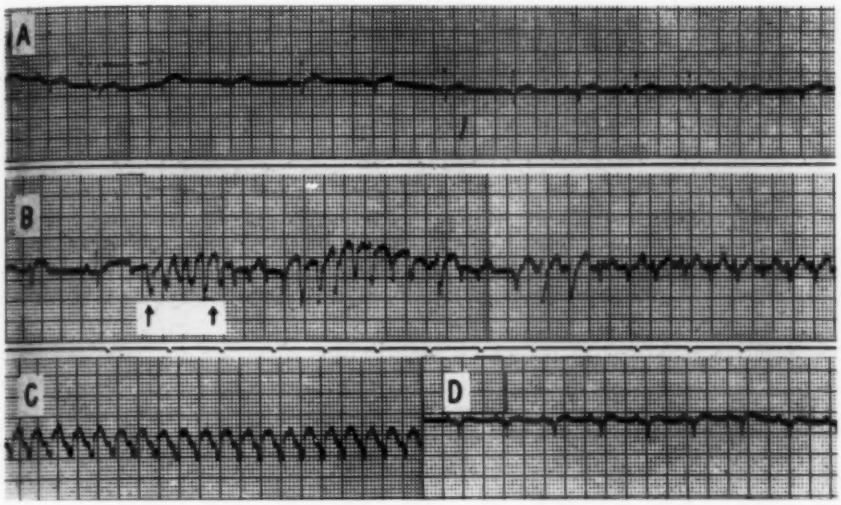

Fig. 5. A. Electrocardiogram before puncture of the left ventricle. B. The injection of contrast material (↑↑) produces many extrasystoles. C. Shortly afterwards ventricular tachycardia occurred. D. After 20 minutes recovery.

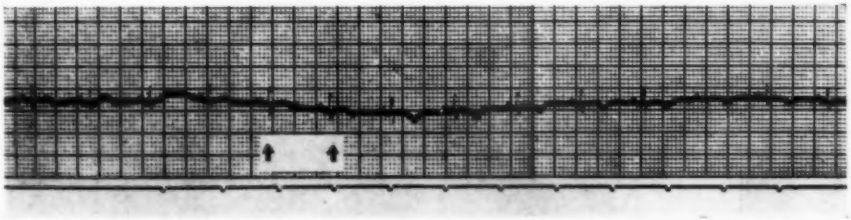

Fig. 6. Electrocardiogram during intrapericardial injection. Acute inversion of T-wave without arrhythmia.

Small clots occurred in the needle when it was not flushed continuously with isotonic saline solution. Continuous slow flushing of the needle with intermittent more rapid injection of small amounts of isotonic saline solution was considered a necessary precaution while the needle remained in the ventricle.

In an earlier model of the cross perforated needle in which the distance between the proximal and distal holes was 1.5 centimeters, difficulties were encountered in placing all the holes within the ventricle. This is understandable when it is realized that the diameter of the cavity of the left ventricle during systole in a small dog heart may be less than

1.5 cm in diameter. When injections were carried out with this needle having widely spaced holes, contrast material occasionally was injected into the myocardium and the pericardial space. Such an injection of contrast material into the myocardium is shown in Fig. 3. Myocardial veins and the coronary sinus were visualized in this way. After ten or fifteen minutes the contrast material had disappeared in control roentgenograms. There were marked electrocardiographic changes when contrast was injected into the myocardium (Fig. 5).

In Fig. 4, the result of an injection of contrast into the pericardium is shown. Some of the coronary vessels are seen in relief in the roentgenogram. The electrocardiogram showed transient T-wave inversion without disturbance of rhythm (Fig. 6).

Such experiences made alterations in the design of the needle necessary, and the distance between the proximal and distal holes was finally shortened to 2 millimeters.

Before injecting the diagnostic dose of contrast material, it seemed important to make test injections. When the needle was not placed properly, a rapid injection of a small amount of saline solution by hand produced extrasystoles. As a final check on the position of the needle, a few milliliters of contrast material were injected manually during exposure of single film. So far as could be determined, no damage resulted from leaving the needle in the ventricle during the time required for development of the film.

A 50 or 70 per cent solution of Urokon was used as the contrast material in the early experiments. In one animal, however, the injection in two-thirds of a second of one milliliter of Urokon 70 % per kilogram of body weight into the left ventricle produced generalized convulsions. Although these disappeared in fifteen minutes, the animal was found dead the following day. After this experience, Hypaque 70 % was substituted and used for the bulk of the experiments at a dose level of 1 milliliter per kilogram body weight. No untoward effects have been encountered when these amounts of Hypaque were used.

Several dogs had multiple ventricular punctures without apparent harm, but one dog with 7 punctures had a large pericardial clot when he was sacrificed at the conclusion of the experiment.

According to experiences collected from these studies the following technique has been accepted as suitable.

Technique of controlled puncture and contrast injection

The anesthetized animal is placed in supine position. The centimeter lead scale is placed in the mid line just below the xiphoid process.

In order to calculate the direction and depth of puncture, roentgenograms are made of the chest in antero-posterior and lateral projec-

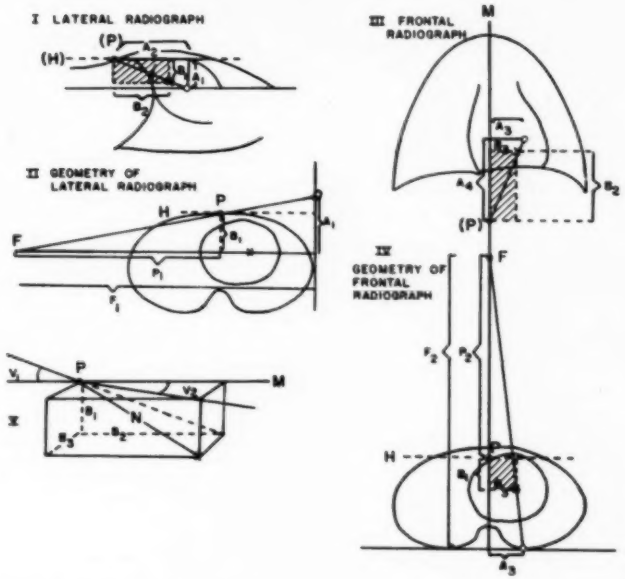

Fig. 7. Triangulation procedure for determining the depth and direction of the needle. A_1, A_2, A_3, A_4 — Measured distances on films; B_1, B_2, B_3 — Distances corrected for geometric distortion; F — Focus; F_1, F_2 — Focus—film distances; H — Horizontal plane through point of puncture; M — Mid sagittal plane of chest; N — Depth of puncture; P — Point of puncture on skin; P_1, P_2 — Focus-puncture plane distances; O — Selected point for needle tip; V_1 — Vertical angulation of needle; V_2 — Horizontal angulation of needle.

$$\text{I)}\ B_1 = \frac{A_1 P_1}{F_1};\quad \text{II)}\ B_2 = \frac{A_2 P_1}{F_1};\quad \text{III)}\ A_4 = \frac{F_2 B_2}{P_2 + B_1};\quad \text{IV)}\ B_3 = \frac{A_3}{F_2}(P_2 + B_1);$$

$$\text{V)}\ N = \sqrt{B_1^2 + B_2^2 + B_3^2}$$

tions. The central beam is projected at the mid line and approximately at the level of the center of the heart for the antero-posterior view. For the lateral view the beam is centered at the same level and mid chest. Focus distances are measured to the film and to the perpendicular planes through the most cranially placed lead marker below the xiphoid process, in both projections.

On the lateral roentgenogram, a point is selected in the heart to which the tip of the needle will be guided. Selection of this point, which ideally should represent the projection of the center of the left ventricle, is one of the more difficult steps in this procedure. Preliminary angiocardiography would probably be of some help, but has not been employed in these experiments. After selecting the prospective site for the needle

tip, the point of puncture on the skin is chosen in reference to the lead centimeter scale. The point is selected from which it appears possible to reach the desired position in the left ventricle passing just posterior to the apex. If the place of puncture does not correspond to the most cranially positioned marker of the lead scale, the focus distance to the perpendicular plane through the chosen point of puncture is calculated. The direction and depth of puncture is then determined according to the procedure of triangulation shown in Fig. 7.

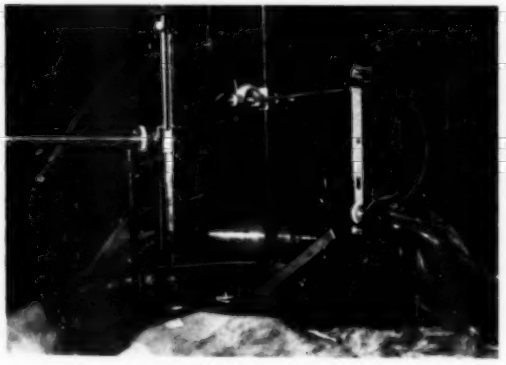

Fig. 8. Arrangement of protractors for guiding the needle.

For determination of the angles it has been convenient to lay out the appropriate distances on paper and adjust the protractors directly. The protractors are set to the proper angles, attached to stands and placed over the animal in relation to the point of puncture (Fig. 8).

The stop is placed on the needle according to the calculated depth of puncture and the skin is cleansed. The pressure injection syringe and the proximal plastic tubing are filled with the calculated dose of contrast material. After the air has been removed carefully, this part of the system is closed with a large bore three-way stopcock. The distal part of the plastic tubing and the needle are filled with isotonic saline solution from the glass syringe attached to the three-way stopcock.

As the needle is slowly flushed with saline solution, it is introduced beneath the skin. The direction of the needle is corrected with the protractor. Under electrocardiographic control the needle is advanced slowly against the heart. When the needle touches the heart it is pushed through the heart wall rapidly until the stop reaches the skin. If the needle is in the proper position, few, if any, extrasystoles should be observed. The presence of numerous extrasystoles indicates an incorrect position of the needle tip. However, slight depression of the needle butt may abolish these extrasystoles. The presence of pulsating arterial blood in the plastic tubing suggests that the tip of the needle is placed in the ventricle. The same sign will be observed if it reached the first part of the aorta. The needle is flushed with small amounts of saline solution. No changes in the electrocardiogram should be detected with rapid injections of 2 to 3 milliliters of saline solution. A final test injection of

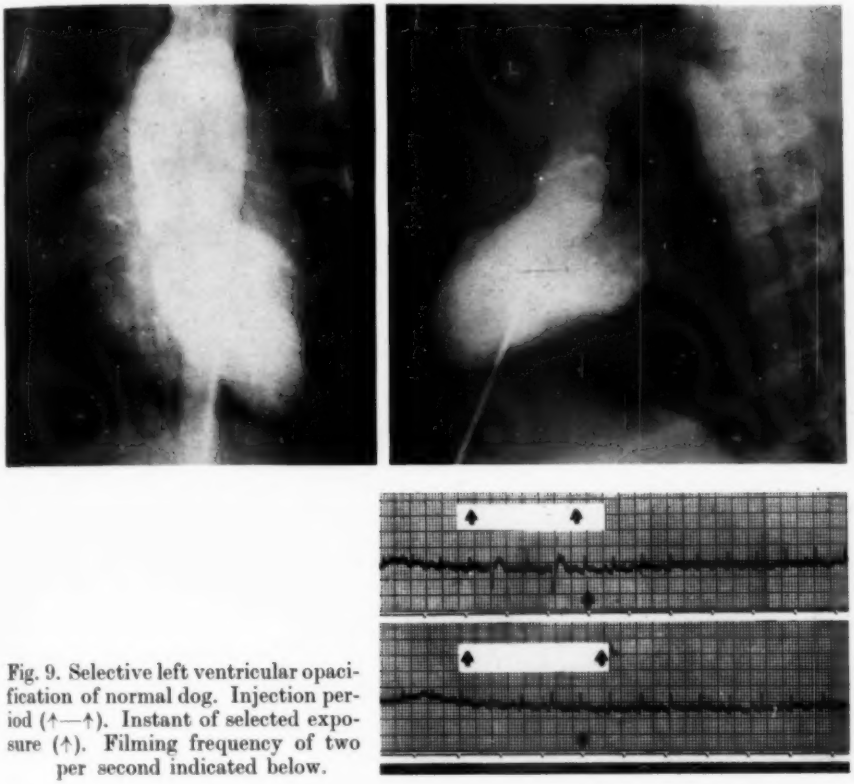

Fig. 9. Selective left ventricular opacification of normal dog. Injection period (↑—↑). Instant of selected exposure (↑). Filming frequency of two per second indicated below.

2 milliliters of contrast medium is then made by hand during exposure of a single film. If no disturbances of the cardiac rhythm occur and the test film shows proper positioning of the needle, the injection of the diagnostic contrast dose is made during exposure of serial films. The needle is then removed although on some occasions during these experiments it has been left in place for a second injection.

If the above described test manœuvres produce electrocardiographic disturbances the needle may be repositioned by slight withdrawal or advance, and the testing repeated. Persistent failure with this slight repositioning requires another puncture. Between testing manœuvres the needle is flushed with saline solution.

Selective left ventricular contrast opacification according to this technique is shown in Fig. 9. One (1) ml Hypaque 70 % per kilogram body weight was injected for each projection.

Additional observations

In two experiments, the effect of moving the needle tip in the ventricle was studied. It was found possible to move and press the needle tip against the ventricular wall in some directions without producing electrocardiographic alterations. A record of such manipulations is shown in Fig. 10.

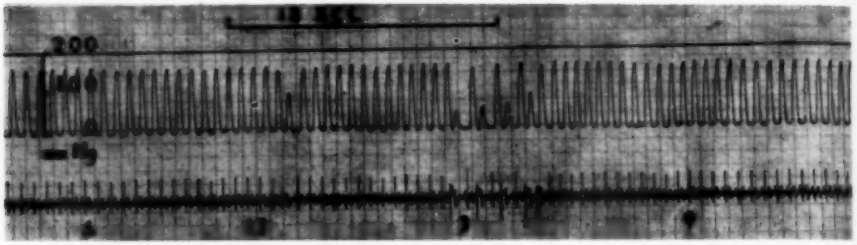

Fig. 10. Left ventricular pressure measurement through the needle while moving the tip against the ventricular wall: downward (6), upward (12), laterally (3), medially (9).

Once the technique was considered acceptable, electrocardiographic observations with standard limb leads were regularly made before the puncture and after withdrawal of the needle. At the conclusion of the experiments there was, however, T-wave inversion in leads II and III in all cases (Fig. 11). In one dog studied again three weeks later these changes had disappeared.

The effect upon left ventricular pressure of rapid injections of fluid in amounts of 1 ml per kilogram body weight was studied on three occasions. A second, 18 gauge needle was placed in the ventricle alongside the cross perforated needle and pressure recorded by an Elema pressure transducer and mingograph direct writer. The extrasystoles that usually occurred during injection may have marked a very slight pressure elevation. On one occasion when no extrasystole occurred such a small systolic pressure elevation could be observed (Fig. 12 A). Injection of Hypaque 70 % caused a transient slight decrease of the systolic pressure and increase in heart rate. An equal amount of 5 per cent dextrose solution caused an earlier and more pronounced decrease in pressure (Fig. 12 B).

Post mortem examinations were performed on 6 dogs. One heart, examined immediately after an experiment where seven punctures were made, clearly showed the punctures, some subendocardial hemorrhage on one of the mitral leaflets, and a large 1.5 × 1.5 × 2 cm clot in the pericardial cavity. In other hearts examined 1 to 3 weeks after the experi-

Fig. 11. Electrocardiograms, Leads I, II, III taken before (*above*) and after (*below*) withdrawal of the needle. T-wave inversion is recorded.

ments, the puncture site could not be located with certainty and no pericardial blood was found. One heart into which contrast material had been injected intramuscularly showed a small scar presumably at the site of injection. Only one dog died as a result of these experiments. In this case the death was obviously related to excessive contrast material in the cerebral circulation.

Conclusions

It has been demonstrated previously in dogs and man that it is possible to puncture and inject contrast material into the left ventricle without producing damage to the heart. The 'blind technique' used in these cases involves, nevertheless, certain hazards and has obvious deficiences. To overcome these an improved technique which has the following features has been developed in dogs:

1. On preliminary roentgenograms the direction of the needle and depth of puncture are calculated by means of triangulation to reach a previously selected point in the heart. The needle is directed to this point with externally placed guides. In this way, the hazards of unsuccessful or multiple punctures may be reduced.

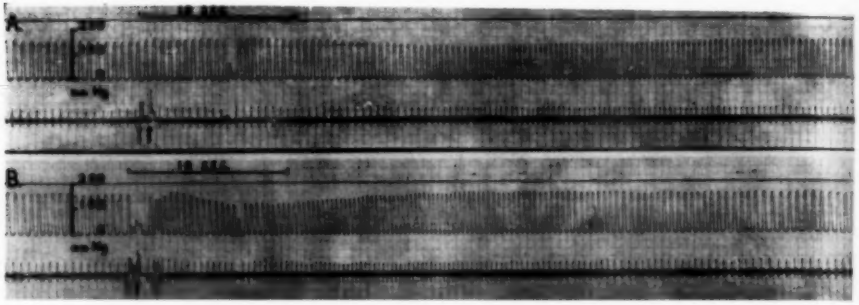

Fig. 12. Left ventricular pressure response to the injection of 1 ml per kg bodyweight. Injection period (↑↑) A. Hypaque 70 %. B. Dextrose 5 %.

2. By utilizing electrocardiogrophic and roentgenographic control of test injections the correctness of needle puncture may be assured and the danger of intramuscular injection of large amounts of contrast material avoided.

3. A special multiple perforated needle has been designed to improve the mixing of contrast material and blood and to avoid positional change of the needle by recoil during the contrast injection.

Furthermore it has been shown that a needle, percutaneously inserted into the left ventricle, can be safely left in place for more than 30 minutes. T-wave inversion noted in the electrocardiogram is not necessarily permanent.

The rapid injection of a 'diagnostic dose' of contrast material through the needle causes occasional extrasystoles but otherwise no change in intraventricular pressure that might be harmful or interfere with natural cardiac function.

This investigation was carried out during Dr. NORDENSTRÖM's tenure of a James Picker Foundation Fellowship in Radiological Research. It was also supported by the John and Mary R. Markle Fund and the Michigan Heart Association.

SUMMARY

A technique of controlled puncture and contrast injection into the left ventricle has been developed in a series of dogs. An especially devised puncture needle to eliminate recoil and to provide good mixing is guided into the left ventricle by means of a procedure of triangulation for determination of puncture depth and direction of the needle. In addition, some control procedures are added to reduce the risks of contrast injection into the myocardium. It is believed that this method will considerably diminish the hazards connected with so called 'blind' methods of left heart puncture for contrast injection into the left ventricle.

ZUSAMMENFASSUNG

An einer Versuchsserie von Hunden wurde eine Technik der kontrollierten Punktion und Kontrastinjektion in die linke Herzkammer entwickelt. Es wurde eine Nadel konstruiert, um den Rückstoss zu vermeiden und um eine gute Mischung zu erhalten, die, mittels der Methode der Triangulierung, zur Bestimmung der Punktionsrichtung und Tiefe, in die linke Herzkammer eingeführt wird. Ausserdem tragen einige Kontrollverfahren dazu bei, die Gefahren einer Kontrastinjektion in das Myokard zu vermindern. Es wird geglaubt, dass diese Methode beträchtlich die Gefahren, die mit der sogenannten 'blinden' Punktionsmethode zur Kontrastinjektion in die linke Kammer verbunden sind, vermindern wird.

RÉSUMÉ

Les auteurs ont mis au point sur une série de chiens une technique de ponction et d'injection de contraste contrôlée dans le ventricule gauche. Une aiguille de ponction spécialement conçue, pour éviter son recul et pour donner un bon mélange, est guidée vers le ventricule gauche grâce à une méthode de triangulation destinée à déterminer la profondeur de la ponction et la direction de l'aiguille. On y associe des méthodes de contrôle pour diminuer les risques d'injection de contraste dans le myocarde. Les auteurs pensent que cette méthode réduira considérablement les risques inhérents aux méthodes dites 'aveugles' de ponction du *coeur* pour injection de contraste dans le ventricule gauche.

REFERENCES

1. Cregg, H. S., Smith, P. W., Wilson, C. W., and Bull, J. W.: Cardioangiography. J. thorac. Surg. 28 (1954), 273.
2. Núñez, B. V., and Ponsdomenech, E. R.: Heart puncture, cardioangiography. Clinical and electrocardiographic results. Am. Heart J. 41 (1951), 855.
3. Nuvoli, T.: Arteriografia dell'aorta toracica mediante punctura dell'aorta ascendente o del ventricolo. Policlinicio 43 (1936), 227.
4. Ponsdomenech, E. E. and Núñez, B. V.: Heart puncture in man for diodrast visualization of the ventricular chambers and great arteries. The experimental and anatomico-physiological bases and technique. Am. Heart J. 41 (1951), 643.
5. Reboul, H. and Racine, M.: La ventriculographie cardiaque expérimentale. Presse méd. 41 (1933), 263.

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ROENTGEN TREATMENT OF MYELOMA WITH SPECIAL CONSIDERATION TO THE DOSAGE

by

Torsten Norin

Cases of myeloma have previously been regarded as comparatively rare although they seem to have increased in number during recent years (DALGAARD). A plausible explanation may be that changes, which earlier would have been regarded as skeletal metastases from an unknown primary tumour, have been proved, by a more accurate diagnosis, to be myelomata.

The increasing number of cases of myeloma has raised the question of the possibility of roentgen treatment in connection with this condition. One of the problems discussed has been the irradiation sensitivity of a myeloma. Since this problem has not been definitely solved the present investigation was undertaken to elucidate the question of roentgen treatment to local centres and the doses required to heal the lesions.

Literature survey. There is only very sparse information in the literature as to the doses required to heal the tumourous tissue in myeloma. In most papers, it is only stated that moderate doses of roentgen reduce pain in cases of myeloma (SNAPPER, BATTS, NAYLOR). Others (ANDA, BAILEY, BICHEL & KIRKETERP, and HOLDEN), however, report myeloma having been healed after roentgen treatment, but none of these indicate either the dose or the duration of treatment. LEEDHAM-GREEN et coll. describe two cases of myeloma affecting the pelvis, both of which show healing after roentgen therapy. In both these cases, the tumour dose was 4,380 r/28 days and 5,000 r/16 days respectively, and roentgen control after the treatment revealed increased calcification in the centres of destruction. One of these patients lived for two years after the treatment.

GARLAND & KENNEDY (1948) have published a detailed summary on roentgen treatment of myeloma and the doses required to heal myeloma

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centres. In addition to reports in the literature, they describe 18 of their own cases, 11 of which were histologically verified. In 8 of the verified cases there was an objective improvement in one single case only. In this case there was destruction of a vertebra, Th VIII, after a dose of 2,660 r /30 days, and re-calcification as well as improvements in motor function and sensibility were obtained. The authors say: "One might expect some correlation between irradiation dosage and results. The more adequate dosage (up to reasonable limits, say 2,500 r tissue roentgen tumour dose in a period of two to four weeks) might be expected to give improved results. A review of the literature and study of our own dosage result tabulation suggests that this is not the case." In conclusion, the authors distinguish between multiple and solitary myeloma and state ". . . multiple myeloma is not a very radiosensitive disease. Solitary myeloma appears to be a radiocontrollable disease in certain instances and should be treated by vigorous roentgen irradiation when the diagnosis is established microscopically. Multiple and solitary myeloma, with spinal cord compression and paresis or paraplegia, appears to be well worth irradiation (following laminectomy)."

Material. The material on which this investigation is based consists of 30 cases of myeloma, treated at King Gustaf V Jubilee Clinic, Gothenburg, during the period 1943—1953. All the cases were verified pathoanatomically or by sternal puncture. Multiple skeletal destructions occurred in all the cases.

Method. Roentgen treatment was given in all cases to one or several centres, the factors being 170 to 200 kV, 10 to 15 mA, 0.5 mm Cu + 1 mm Al filtration (in some cases with superficial centres the filtration used was 4 mm Al); focus-skin distance generally 50 cm, but in small fields and superficially situated centres, the distance was reduced to 40 cm. The surface of the field varied between 50 to 250 cm^2; the daily dose was, as a rule, 300 to 400 r measured on the skin. In the cases described below the dose to the centres has been calculated. The treatment was administered daily, except on Sundays; in cases of severe leukopenia it was given at intervals.

Lesions have been selected from the present material, in which the effect of the treatment has been objectively registered: 1) palpable tumours, which disappeared after treatment; 2) skeletal destructions, where signs of healing appeared after treatment in the form of roentgenologically demonstrable sclerosis of the centres; 3) compression of the vertebrae where the paraplegia declined after treatment. In 53 lesions, the effect has been checked according to the above. Five of the lesions consisted of tumours in the soft parts and the others of areas of skeletal destruction. In two cases, there was compression of the vertebrae with paraplegia.

In his paper on the cumulative effect of fractional irradiation STRANDQVIST has shown that there is a correlation between the result of treatment and dosage, if consideration is taken both to dosage and to duration of treatment. As a basis for this work, moderately large carcinomas in the face, including the lips, were taken; the optimal dose is shown in diagram 1 (healing of carcinoma of the skin).

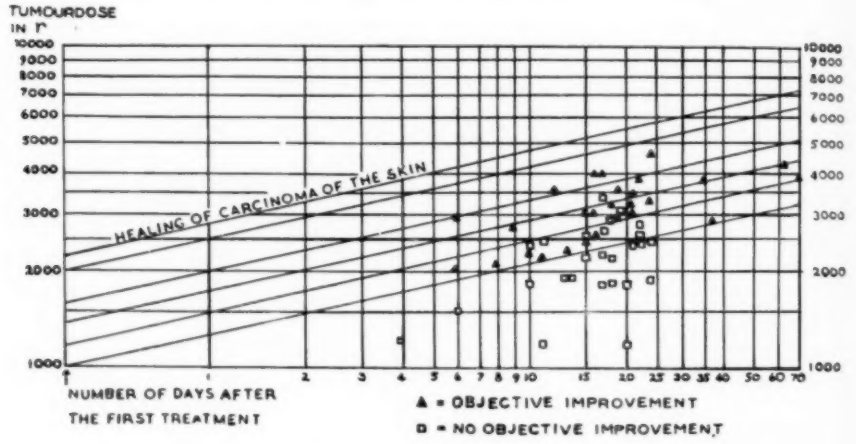


Diagram 1. Fractionation diagram illustrating the results of roentgen treatment to 53 myelomatous lesions.

In this investigation I have assumed that when treating myeloma with roentgen radiation there is also a cumulative effect, and I have therefore, when calculating the required dose for healing myeloma centres, used STRANDQVIST's fractionation diagram. The centre doses obtained have been plotted to this schedule.

The effective tumour dose for centres treated differently may be compared by referring to the so-called cumulative dose (= assumed single irradiation). The tumour dose of 2,000 r for eight days, for instance, gives a cumulative dose of 1,000 r.

Results

The irradiation resulted in reduction of pain in all cases. Objective improvement occurred in 27 lesions while the other 26 showed no objective improvement.

In this material there was no sign of objective improvement in any of the cases in which the tumour dose was below a cumulative dose of

1,000 r. The number of centres where objective improvement could be registered in connection with an increasing cumulative dose is seen in Table 1.

Table 1

Cumulative dose in r	Objective improvement in number of cases	No objective improvement in number of cases
< 1,000 r	0	17
1,000—1,200	8	6
1,200—1,400	10	2
1,400—1,600	5	1
1,600—1,800	4	0

As is seen from the table the optimal doses (with a high healing frequency) to myeloma centres lie on a dose level corresponding to a cumulative dose of about 1,500 r (see Diagram 1), for instance a tumour dose of 3,400 r during 15 days, or 4,000 r during 30 days.

The time of observation after completed treatment has varied from six months to five years (Table 2).

Table 2

Time of observation after treatment	Number of cases
0— 6 months	0
6—12 "	8
12—18 "	8
18—24 "	—
> 24 "	11

In two of the cases showing an objective improvement, progress in the condition later occurred. In Case 3 there was a destruction in the pelvis, which after 21 months increased slightly in size. This destruction had been previously treated with a centre dose of 3,200 r during 21 days, cumulative dose about 1,300 r. In Case 4 progression of a lesion in the ribs occurred 12 months after treatment. This centre had received a dose of 4,000 r for 71 days (cumulative dose about 1,300 r).

Case reports

Case 1. O. K. Male. Increasing pain in the back for about 15 months. In January 1951, after two days of severe pain, the patient developed total paresis in both legs with signs of compression of the spinal cord at the level of ThV. The diagnosis was uncertain, but *laminectomy* was performed with an attempt to remove a tumour originating from Th VI; this proved to be a myeloma. After the operation, there was a slight improvement of sensibility and motor function. *Roentgen treatment* was started 18 days after the operation, and was given to two dorsal fields (175 and 150 cm², 195 kV, and other factors as previously given). During the treatment, there was an interval of 20 days, as the patient developed pneumonia. The patient received a calculated tumour dose of 2,820 r for 37

days and gradually improved. Five years after treatment he wears a corset and walks without pain with a stick. The roentgen appearances of the affected vertebra have not changed since the first control after the operation. Repeated *roentgen examinations* of other parts of the skeleton have shown the presence of further areas of destruction. In May 1955, the patient received *roentgen treatment* to an affected rib.

Case 2. R. T. Male. Periodic pain in the back for two years. In January 1954, the patient consulted a chiropractor who "adjusted" the spinal column. The following day the patient had severe pain and difficulty in moving. There was reduced power in both legs and reduction of sensibility as well as difficulty with micturition and defaecation, followed by complete paraplegia. *Roentgen examination* revealed that Th XII was to a great extent destroyed and compressed, the fragments being displaced. Sternal puncture showed an increase in the plasma cells, and electrophoresis revealed a considerable increase in the γ-globulin fraction.

Roentgen treatment was given to two dorsal fields (each with a surface of 100 cm²) directed towards the affected vertebra, with the same factors as previously mentioned; calculated tumour dose 2,950 r during 19 days. The pain ceased almost entirely during the treatment. On admission, the patient had complete paresis of the bladder, but one week after the treatment had no residual urine. The function of the bowels was also normal.

The patient has later had destructive lesions in other skeletal parts. He can now walk with a stick comparatively freely two years after the treatment. *Roentgen examination* after treatment showed that the condition in the compressed vertebra was unchanged. No additional compression has occurred.

Case 3. E. B. Male. In 1950, the patient had pain in the left hip-joint. *Roentgen examination* showed considerable destruction of the left ilium. Biopsy revealed a plasma-cell myeloma. *Treatment* began in August 1951. Roentgen examination then showed extensive bone destruction. There was also a mass the size of half a mandarine in the left breast which also proved to be a myeloma.

Roentgen treatment was given to the left side of the pelvis from one anterior, one lateral, and one dorsal field. Field surfaces 275 cm², 375 cm², and 325 cm²; irradiation factors as previously mentioned. The total skin dose was 2,400 r on each field with a calculated tumour dose of 3,200 r during 21 days. Roentgen treatment was also given to the tumour in the left breast from two tangential fields (175 cm² and 200 cm²). Focus—skin distance 50 cm, otherwise the same irradiation conditions as above. Each field was loaded with a total dose of 2,000 r with a calculated tumour dose of 3,600 r during 12 days.

When the treatment was completed, the pain in the hip had almost disappeared and the resistance in the breast had decreased considerably. At the follow-up examination one year later the patient had no hip trouble. The roentgen examination showed a more satisfactory demarcation with increased calcification. The tumour in the left breast had disappeared.

A large tumour was now present, however, in the right breast. *Roentgen examination* revealed that there was a cyst-like appearance of the right acromial process with a defect in the contour.

The patient received *roentgen treatment* to the right breast as previously to the left with a calculated tumour dose of 3,600 r during 19 days. At the same time roentgen irradiation treatment was given to the right shoulder from one anterior field (350 cm²), one lateral field (150 cm²), and one dorsal field (250 cm²). Focus—skin distance 50 cm, otherwise the same irradiation conditions as previously. The calculated centre dose was 4,000 r during 17 days. The pain decreased considerably and the tumour in the breast became smaller. At the follow-up examination two months later, the patient had no trouble from the shoulder. Roentgen control showed a distinct increase of calcification in the involved

area in region of the acromion process. The mammary tumour had become very small and disappeared after another two months.

At a further roentgen control there was now a lesion in the left scapula. Roentgen treatment was given from a large frontal (175 cm²) and a dorsal field (275 cm²). Both fields were loaded to 3,200 r with the same irradiation conditions as mentioned above and a calculated centre dose of 3,500 r during 21 days.

One year and nine months after the roentgen treatment of the pelvis had terminated, a further control showed regression. Additional roentgen treatment was given. The disease progressed, however, and the patient died two years and eight months after admission to hospital.

Case 4. G. B. Male, aged 40, with three months history of pain in the right leg. *Roentgen examination* after trauma showed destruction in the upper part of the right femur. Three months later, on 12 September 1948, a spontaneous transverse fracture occurred through the affected area. *Roentgen treatment* was given, from 7 to 22 October, to two frontal fields directed to the lesion (factors as previously mentioned). Field surfaces 250 cm² and 200 cm²; both fields were loaded to 2,800 r which gives a calculated tumour dose of 2,460 r during 15 days. Additional treatment was also given to a dorsal field, in January 1949

a b

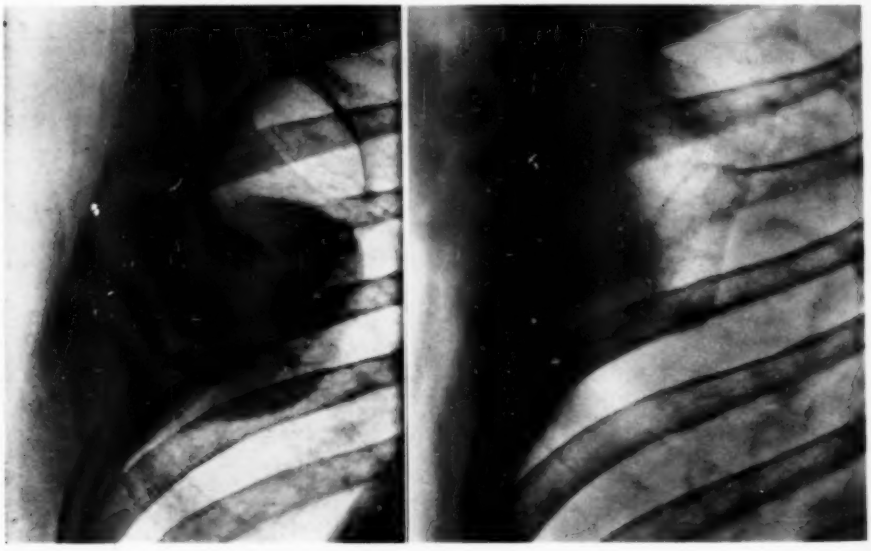
Fig. 1. Case 4. Myeloma of femur with pathologic fracture. a) Before treatment. b) Two years after treatment.

(field surface 300 cm² irradiation; conditions otherwise as mentioned). A tumour dose of 1,230 r during 8 days was given. Repeated roentgen examinations showed increasing stabilization and healing (Fig. 1). A follow-up examination in March 1951, showed new areas of destruction in the lower part of the right femur; no progress or changes in the part of the femur previously treated.

Roentgen examination in October 1949 of the left half of the thorax revealed a defect in the 5th rib with a mass extending into the thorax. Treatment was given to three fields, which were each loaded with a skin dose of 2,800 r. The tumour dose was 4,000 r during 71 days. Roentgen control in February 1950 showed some changes persisting, and an extra dose of radiation was given from 2 fields, 2 and 3 × 400 r, respectively. Roentgen control in October 1950 indicated that the destruction was very much less pronounced and the cortex to a large extent re-formed (Fig. 2).

Roentgen control one year and five months after the treatment had terminated, showed further changes in the rib. The patient received roentgen treatment to various lesions and was treated with P^{32} as well. In July 1952 he died, three years and nine months after the first roentgen treatment had been started.

As has previously been pointed out, myeloma has been considered to be rather sensitive to irradiation. Despite this, only very few cases have been described in which healing has occurred after roentgen treatment. GARLAND & KENNEDY point out in their paper that a dose of 2,500 r during 15 to 30 days is not sufficient to heal myeloma centres.



a b

Fig. 2. Same case as in fig. 1. Myeloma of rib, bulging into thorax. a) Before treatment; b) Ten months after treatment.

If the centre doses with which GARLAND & KENNEDY have treated their patients are compared with those in Fig. 1, they will be found to be lower than the level of optimal doses indicated. GARLAND & KENNEDY, however, describe a case in which objective improvement was observed after a tumour dose of 2,600 r/30 days, which corresponds to a cumulative dose slightly lower than 1,000 r. In the two cases described by LEEDHAM-GREEN et coll., where there was an objective improvement, the cumulative dose clearly lies above the optimal dose of 1,500 r.

As with most tumours, myelomata have a varying irradiation sensitivity. Our experience, as well as certain data in the literature have shown that it would be desirable to achieve a cumulative dose of 1,500 r in order to obtain a high healing percentage of myeloma centres. According to STRANDQVIST, the corresponding cumulative centre dose for skin cancer is 2,200 r. Myeloma centres should thus be regarded as tumours with a moderate irradiation sensitivity.

All this shows that it is necessary to use much higher doses for myeloma than is otherwise usual.

With myelomas which are still solitary, an attempt should be made to achieve the cumulative centre dose of 1,500 r, or more, in order to obtain a permanent healing and thus prevent any further development of the disease. In solitary very early cases it should also be possible to obtain definite healing of the condition by adequate dosage. In multiple myeloma, the centres which are of the greatest danger to the patient should be adequately treated, *e. g.*, a compressed vertebra or a centre of destruction in a long bone. If possible, the roentgen treatment should be completed to the same dosage as for an isolated centre, *i. e.*, a cumulative dose of 1,500 r. Of the cases described it is quite obvious that by such a treatment the patient's condition may be controlled much more satisfactorily, as it is not necessary to calculate on regression in the areas subjected to irradiation.

SUMMARY

Thirty cases of verified myeloma which received roentgen treatment to 53 different centres have been examined. Special consideration has been given to the doses which are required for healing myeloma centres, in 27 of which signs of permanent healing have been noted. The results show that the lesions only have moderate irradiation sensitivity, and that a cumulative (according to STRANDQVIST) dose of 1,500 r is required to produce healing.

ZUSAMMENFASSUNG

Dreissig histologisch sichergestellte Myelomfälle, bei welchen 53 verschiedene Herde röntgenbestrahlt wurden, sind untersucht worden. Besonders wurden hierbei die zur Ausheilung von Myelomherden erforderlichen Dosen berücksichtigt; 27 Herde wiesen

Anzeichen einer permanenten Heilung auf. Die Resultate zeigen, dass die Veränderungen nur eine mässige Strahlenempfindlichkeit besitzen und dass eine kumulative Dosis (nach STRANDQVIST) von 1,500 r erforderlich ist, um eine Ausheilung zu erzeugen.

RÉSUMÉ

L'auteur a examiné trente cas de myélomes vérifiés, qui ont été traités par radiothérapie sur 53 foyers myélomateux différents. Il s'est attaché particulièrement à déterminer les doses qui sont nécessaires pour guérir les foyers myélomateux; sur 27 de ces foyers on a enregistré des signes de guérison durable. Ces résultats montrent que ces lésions n'ont qu'une radio-sensibilité modérée et qu'une dose cumulative (d'après STRANDQVIST) de 1,500 r est nécessaire à la guérison.

REFERENCES

ANDA, L.: Multiple myeloma. Acta radiol. 33 (1950), 515.

BAILEY, C. O.: Plasma cell myeloma of the humerus treated by roentgen radiation. Am. J. Roentgenol. 36 (1936), 980.

BATTS, M.: Multiple myeloma: Review of 40 Cases. Arch. Surg. 39 (1939), 807.

BICHEL, J. and KIRKETERP, P.: Notes on myeloma. Acta radiol. 19 (1938), 487.

DALGAARD, J. B.: Solitaere og multiple plasmocytomer (myelomer). (Danish.) Nord. Med. 53 (1955), 648.

GARLAND, H. and KENNEDY, B. R.: Roentgen treatment of multiple myeloma. Radiology 50 (1948), 297.

HOLDEN, H.: Solitary plasmocytoma of the bone: Report of a case. Brit. Med. J. 1949, p. 437.

LEEDHAM-GREEN, J. C., BROMLEY, J. F. and RABAN, J.: Plasmocytoma of the innominate bone. Brit. J. Surg. 26 (1938), 90.

NAYLOR, A. and CHESTER-WILLIAMS, F. E.: Myelomata of bone: A review of 25 cases. Brit. Med. J. 1954, p. 120.

SNAPPER, I., TURNER, L. B. and MOSCOVITZ, H. L.: Multiple myeloma. GRUNE & STRATTON, New York 1953.

STRANDQVIST, M.: Studien über die kumulative Wirkung der Röntgenstrahlen bei Fraktionierung. Acta radiol. Suppl. 55 (1944).

FROM THE C.H.F. MÜLLER A. G. LABORATORY, HAMBURG, GERMANY

ON THE DETERMINATION OF ROENTGEN TUBE FOCAL SPOT SIZES BY PIN-HOLE CAMERA ROENTGENOGRAPHY

by

A. H. G. Kuntke

The method of determining the size of the focal spot of a roentgen tube by reproducing it on a film by means of a pin-hole camera is as old as roentgen technique itself. It was indeed applied by W. C. RÖNTGEN in his fundamental work.

The laws governing pin-hole roentgenography are elementary: if a pin-hole, the diameter (d) of which should preferably be a fraction of the linear dimensions of the focal spot, is at a distance g from the latter, and if the distance between the pin-hole and the film is b, the image of the focal spot appears enlarged (or reduced) by the ratio $m = \frac{b}{g}$. In consequence of the dimension of the pin-hole, however, some degree of blurring is introduced. This is because each point of the focal spot is reproduced as a circular area having a diameter of $\frac{g + b}{g} d = (m + 1) d$.

If the entire area of film blackening, inclusive of the blurring, be taken into account when measuring the image, any given dimension of the focal spot (length, breadth, or diameter) which has a true value of F will appear to be increased in size. The measured size (S) will, in fact, be given by:

$$S = Fm + (m + 1) d$$

Alternatively, when calculating the focal spot dimension F from the corresponding dimension S on the film, the following equation applies:

$$F = \frac{S}{m} - \left(1 + \frac{m}{1}\right) d \qquad (1)$$

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or, in the more specific and more familiar case where $g = b$ (*i.e.* $m = 1$):

$$F = S - 2d \qquad (1\text{ a})$$

This relationship has often been used for the calculation of the size of the focal spot (BEESE, THORP), although BRONKHORST in 1927 drew attention to the fact that correction by the amount of the total penumbra $\left[i.e.\left(1 + \frac{1}{m}\right)d\right]$ is inadmissible.

POLANSKY and O'CONNOR have recently occupied themselves anew with the question of determining the true dimensions of a focal spot from its pin-hole image.

They reproduced the circular face of a small radio-active cobalt cylinder, the dimensions of which were known, on a film by means of a pin-hole camera and found that the correct size could be calculated from the pin-hole image by determining the breadth of the latter, including the entire penumbra, by micro-densitometric registration of the variation of the density across the image. After applying the correction according to equation (1), they obtained the true size of the object.

They have used the same method for determining the focal spot dimensions of roentgen tubes. In this case they stated that by means of micro-densitometric measurement of the focal spot image, taken with pin-holes of up to approx. 20 % of the focal spot dimension on fine-grain film, focal spots of 1 mm or larger may be determined with an accuracy of ± 5 % after correction according to equation (1). On the other hand, the same images, measured directly on the film with a scaled $\times$ 8 magnifier, yielded dimensions which were considerably too small after correction according to equation 1.

The suggested micro-densitometric process is, however, time consuming and demands the use of apparatus which is not always available.

In the following, we shall discuss methods which may be applied in order to determine the true size of the focal spot by direct measurement of the focal spot image by means of a $\times$ 8 magnifier with approximately the above mentioned accuracy.

It is desirable firstly to establish how much of the penumbra is actually measured by this visual method, since the results obtained by POLANSKY and O'CONNOR prove that the penumbra is obviously not fully taken into account when measuring with a magnifier.

For this purpose a simple experimental arrangement, as shown in Diagram 1, was chosen. A roentgen tube was selected having a square focal spot measuring 1.2 $\times$ 1.2 mm and a uniform distribution of radiation intensity over its focal area. A thin lead plate with a slit exactly 1 mm in width was fixed at a distance of 50 cm from the focal spot. Roentgenograms on dental films were made at varying distances from

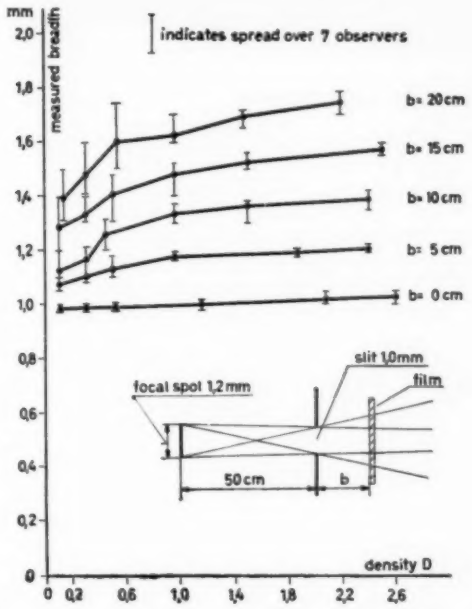

Diagram 1. The influence of density on the measured widths of the strips. Diagrammatic representation of experimental arrangement.

the slit. In each position exposures of varying time were made in order to determine the influence of density upon accuracy of measurement. Since one edge of the focal spot was aligned parallel to the slit, the distribution of the radiation impinging on the film could be determined accurately from the geometric dimensions used in the experiment.

Roentgenographic strips of varying unsharpness were thus obtained, the apparent widths of which were measured by seven observers using a scaled $\times$ 8 magnifying glass. The mean values of the results, as well as their extremes of deviation, are shown in Diagram 1.

We find: a) that the widths obtained by measurement increased as both blurring (distance b) and density (exposure time) increased; b) that as blurring (distance b) increased, the spread (from observer to observer) of measured values also increased. This was especially true at low densities.

In Diagram 2, the distributions of intensity calculated for the various distances between slit and film are shown, together with mean values of the widths measured, these depending on the various densities of the strips.

The image showing absolutely sharp edges, which is obtained at zero

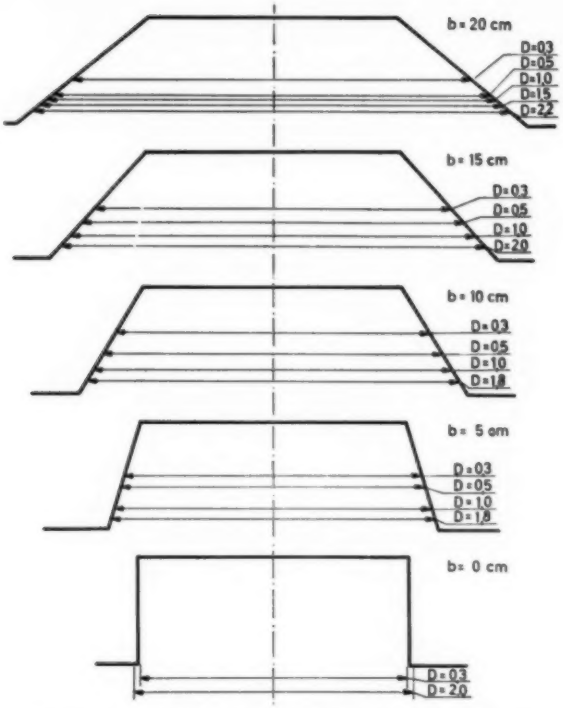

Diagram 2. Calculated distribution of intensity and apparent breadth shown as functions of density.

distance, is correctly reproduced almost independent of the density, as can be seen in the Diagram 1. The deviation here depends on the degree of accuracy of measurement.

In the case of all blurred strips, however, we find that with a density of 0.3, half the blurred area is measured, and with $D = 0.8$ to 1.0 about three-quarters, and that even a density of 2 is not sufficient to reproduce the entire blurred area. If we apply this result to the evaluation of focal spot images, it then means that an image which has a density of 0.3 needs no correction, and that one which has a density of 0.8 to 1.0 need only be corrected by half the amount of $\left(1 + \frac{1}{m}\right) d$. The subtraction of the full correction amount $\left(1 + \frac{1}{m}\right) d$ is not even justified with $D = 2$. One could conclude from this that focal spot images should be so exposed that they have a density of 0.8 to 1.0, and that the dimension of the

focal spot may be determined by using half the correction of equation (1), that is

$$F = \frac{S}{m} - \left(1 + \frac{1}{m}\right)\frac{d}{2} \tag{2}$$

or in the specific case wherein $b = g$ (*i. e.* $m = 1$): (2 a)

$$F = S - d$$

Without doubt this method is superior to that based upon equation (1). However, it is not absolutely satisfactory. It presupposes that the radiation intensity at the edge of the focal spot drops sharply to zero. This assumption, however, will only be approximately correct, because the sharpness of the focal spot edge depends on the distribution of the electrons in the electron beam. For example, in a line focus, the intensity of radiation will as a rule drop more steeply along the breadth of the focal spot than along its length. From the investigation conducted by KLASENS (5) into the combination of unsharpnesses, according to which the total unsharpness equals the cube root of the sum of the third powers of the individual unsharpnesses, we may conclude that a correction for pin-hole unsharpness is inadmissible if the inherent unsharpness of the focal spot edge is equal to or greater than the geometrical unsharpness caused by the pin-hole.

We see that we do not eliminate this uncertainty until we make the pin-hole extremely small. In practice, however, it is sufficient to fulfil the equation

$$\left(1 + \frac{1}{m}\right) d \leqq 0.1\ F$$

This means that in the case of a camera ratio of 1 : 1, the pin-hole diameter is 5 % or less of the dimensions F of the focal spot to be measured, and, in the case of $\times$ 3 magnification, 7.5 % or less. In this case the inherent unsharpness of the focal spot edge is usually equal to or greater than the geometrical unsharpness, and hence all corrections can be dispensed with in determining the size of the focal spot. A still smaller pin-hole, whilst increasing the definition of the focal spot elements, would not improve the inherent edge unsharpness as the latter is no longer a function of pin-hole diameter.

POLANSKY and O'CONNOR have similarly discussed the possibility of reducing the diameter of the pin-hole, and cite the following disadvantages:

1. The exposure time is too long.
2. The length of the hole must be limited so that no 'tunnel effect'

appears. Thus

3. the thickness of the diaphragm will be so small that transmission through the diaphragm material will occur, causing a troublesome background fogging to be superimposed on the focal spot image.

These three points will be discussed in turn below.

1. The smallest hole diameter which can be produced mechanically in a cylindrical form lies in the region of 0.030 to 0.035 mm. It has been found that with such a pin-hole, focal spot images may be produced in quite reasonable times, even with roentgen tubes having stationary anodes, and more so in the case of tubes with rotating anodes because the specific radiation intensity with short time loads is about 8 times as great.

2. The length of the cylindrical hole may, without introducing an intolerable degree of tunnel effect, be as much as five times the diameter. The distribution of brightness for this relationship, as a function of the tangent of the angle of incidence (α), is represented in Diagram 3. This shows that with a field diameter of 12 mm, at a distance of 150 mm, the peripheral brightness is 75 % of that at the centre of the field. We recommend, therefore, that in order to ensure adequate brightness over the focal spot image, the focus be positioned so as to lie within a circle of 12 mm, at a distance of 150 mm.

3. Adopting the relationship length of hole $= 5d$, this would result in a plate thickness of only 0.195 mm ($d = 0.035$ mm). Even when made of a heavy metal such a plate would be too thin to prevent radiation transmission causing undesirable background fogging. It is essential, of course, that the background intensity shall be negligible compared to that of the focal spot image.

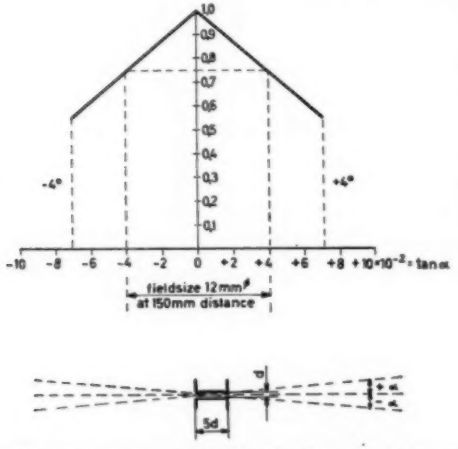

Diagram 3. 'Tunnel effect' of a pin-hole of diameter d and length $5d$. Brightness as function of the tangent of the angle of incidence α.

If a focal spot with an area of A has a specific radiation intensity of R, and f is the area of the pin-hole, then the intensity J_A in the focal spot image is given by

$$J_A = Rf\left(\frac{1}{m}+1\right)^2 \frac{1}{(b+g)^2}$$

whereas the background intensity is

$$J_B = RAT\frac{1}{(b+g)^2}$$

in which T stands for the transmission through the diaphragm

material. Since a high degree of contrast is required, the ratio J_A to J_B should be as large as possible. This will be achieved if

$$I\left(\frac{1}{m}+1\right)^2 \geqslant A.T \tag{3}$$

With a given pin-hole, the background intensity therefore increases:

a) the larger the focal spot area A becomes;

b) the higher the transmission is, *i. e.* the higher the tube tension and the lower the absorption by the metal diaphragm;

c) to a small degree with the enlargement m.

In order to reduce transmission as far as possible, thicker diaphragms having a more suitable form were developed and tested. They have a cylindrical hole of diameter d and length 5 d which continues into a narrow conical hole which opens at an angle of 8°. In addition, an alloy of 90 % gold with 10 % platinum was used as diaphragm material, which combines good mechanical processing qualities with a maximum degree of absorption (even higher than that of tungsten). The diaphragms were manufactured by DEGUSSA (Deutsche Gold- und Silberscheideanstalt) Hanau/Germany.

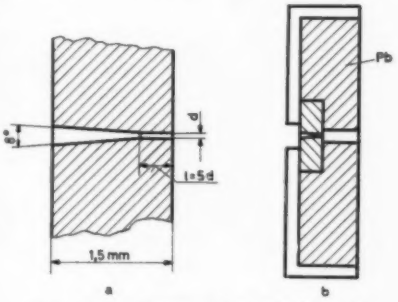

Fig. 1. a. Form of a pin-hole in gold diaphragm. b. Diaphragm fixed in lead holder.

Fig. 1 a shows the form of the diaphragms developed. Two diameters of pin-hole are considered suitable, namely 0.035 mm and 0.100 mm. To facilitate handling, it is best to fit the diaphragms into a holder as shown in the figure b. The 0.035 mm diaphragm is intended for focal spots with linear dimensions of 0.3 to about 2.5 mm. With this exposures can be made with tube voltages as high as 200 kV and focal spot areas up to 5 mm² without visible background. Focal spots of less than 1.0 mm are best photographed enlarged by a factor 2 or 3. If focus pictures at tube voltages of the order of 300 kV were taken using the 0.035 mm pin-hole, the amount of transmission (T) would prove intolerable. This effect may be counteracted by selecting a 0.100 mm pin-hole, thus increasing the intensity J_A of the focal spot and maintaining a satisfactory ratio of intensities ($J_A : J_B$). The 0.1 mm diaphragm is quite suitable for focal spots of 2.5 mm and over, and focal spot areas up to 25 mm². The focal spots should be photographed on fine-grain dental film with a density of 0.5 to 0.9. For measuring, a scaled 8 × magnifier is used.

Calculation of definition obtained with the 0.035 mm diaphragm when using 200 kV unfiltered radiation. Although the experimental exposures have shown that the above-mentioned diaphragm can still be used at 200 kV, as far as diaphragm transmission and background density are concerned, it was still necessary to check that the transmission at this voltage, through the diaphragm material immediately adjoining the hole, did not produce the effect of an enlargement of the pin-hole diameter. For small angles and radiation near the axis of the camera as used in focal-spot roentgenography, radiation which only passes through the pin-hole will reproduce every point of the focal spot by a tiny radiation cylinder as shown in Diagram 4 a. However, in the case of transmission through the region adjoining the pin-hole, this small cylinder will 'flare' at one end as shown in Diagram 4 b. It can be proved that a focal spot edge at which the radiation intensity drops sharply from a high value to zero will be transformed on the film into an increase in energy corresponding to that obtained when the increase in volume of this cylinder is calculated by successive integration between limits, the ultimate limits being x and y. The shape of the 'flare' of the intensity cylinder is calculated from the measured gold absorption with 200 kV radiation filtered with 3 mm Al. By means of graphical integration, the distribution of intensity was calculated both for the 200 kV radiation and for a radiation which did not penetrate the surroundings of the pin-hole. The result is shown in Diagram 4.

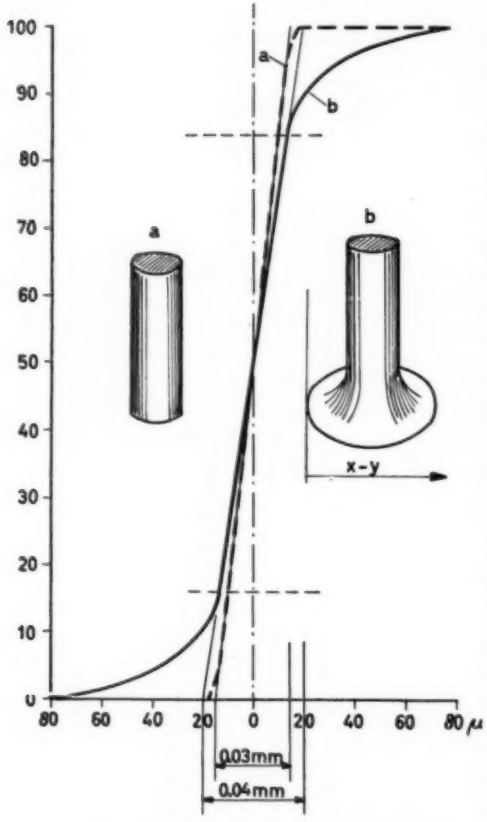

Diagram 4. Calculated geometric unsharpness of a 0.035 mm pin-hole: radiation through pin-hole only (a); with transmission through area surrounding pin-hole at 200 kV (b).

It should be noted here that the absorption curve used as the basis of the calculation, is obtained as usual by the measurement of ionization. The roentgenographic effect, however, decreases relative to this with increasing hardness of radiation. This means that the sweep of the curve of unsharpness at 200 kV is less than is represented in Diagram 4.

If we apply to the curves obtained KLASENS' method which consists of determining the linearly increasing unsharpness which has the same visible effect, and is expressed by a straight line passing through 0.16 and 0.84 of the maximum intensity, we find that for soft radiation the hole of 0.035 mm diameter is only equivalent to a linear increase in unsharpness of 85 % of the diameter of the hole, namely 0.030 mm; on the other hand with focal spot roentgenographs taken at 200 kV, the effective diameter of the pin-hole increases to 0.04 mm. The apparent enlargement of the diameter of the hole is thus relatively small and has negligible influence on the results.

Conclusions

Films are exposed to unsharp roentgen beams the intensity distributions of which are known. The apparent breadth of the strips of differing density which are thus obtained are measured visually by means of a scaled magnifier and compared with the real intensity distribution. From this it would be possible to make a suitable correction of a pin-hole image for determining the real focal spot dimensions, if the focal spot radiation dropped sharply to zero at its edges. But usually the focal spot edge has an inherent unsharpness, which makes the correction uncertain. The solution lies in a considerable reduction of the pin-hole diameter

$$\text{equal to } \frac{F}{10\left(1+\frac{1}{m}\right)} \text{ or less.}$$

(F = focus dimension, m = magnification.)

Then any correction becomes superfluous, because the inherent unsharpness of the focal spot edges is the same as, or greater than that resulting from the pin-hole.

Two diaphragms having pin-hole diameters of 0.035 mm and 0.100 mm are used and these, by virtue of their composition and design, guarantee that transmission through the diaphragm, apart from the pin-hole is maintained at a tolerable level. The diaphragm with a 0.035 mm hole is usable for tube tensions up to 200 kV, whereas that with a 0.100 mm hole can still be used at tensions in excess of 300 kV. For

the 0.035 mm diaphragm at 200 kV, the effective increase in diameter, produced by transmission through the diaphragm material in the area immediately surrounding the pin-hole, is determined and found to be negligible.

SUMMARY

The author shows that the determination of the dimensions of a focal spot by means of its pin-hole camera photograph involves a factor of uncertainty. Only when care is taken, by decreasing the diameter of the pin-hole, that the geometrical unsharpness caused by the pin-hole is equal to, or smaller than the inherent unsharpness of the edges of the focal spot, may reliable results be expected, since then no corrections will be required. Pin-hole diaphragms with 0.035 mm and 0.1 mm diameter holes are employed, the material and shape of which permit them to be used with tube tensions up to 200 kV, and 300 kV, respectively.

ZUSAMMENFASSUNG

Es wird dargelegt, dass die Ermittlung der Abmessung eines Brennflecks aus seiner üblichen Lochkamera-Aufnahme mit einer Unsicherheit behaftet ist. Erst wenn durch Verringerung des Blendenlochdurchmessers dafür gesorgt wird, dass die vom Lochdurchmesser herrührende geometrische Unschärfe gleich oder kleiner ist als die innere, von der Elektronenbelegung im Brennfleck herrührende Kantenunschärfe, sind zuverlässige Resultate zu erwarten, weil dann keine Korrekturen erforderlich sind. Es werden Lochblenden mit 0.035 mm und 0.1 mm Lochdurchmesser angegeben, die in Material und Form so bemessen sind, dass sie bis 200 bzw. 300 kV Röhrenspannung verwendbar sind.

RÉSUMÉ

L'auteur montre que la mesure des dimensions du foyer d'un tube radiographique au moyen de sa chambre noire à trou comporte une incertitude. Ce n'est que quand on prend soin, en diminuant le diamètre du trou, de rendre le flou géométrique dû au trou égal, ou inférieur au flou des bords du foyer, qu'on peut espérer des résultats exacts, car les corrections deviennent alors inutiles. Il se sert de trous-diaphragmes de 0.035 mm et de 0.1 mm de diamètre, dans une matière et d'une forme qui permettent de les utiliser sous des tensions allant respectivement jusqu'à 200 et 300 kV.

BIBLIOGRAPHY

Beese, N. C.: The focussing of electrons in X-ray tubes. Rev. Sci. Instr. 8 (1937), 258.

Bronkhorst, W.: Kontrast und Schärfe in Röntgenbild, s. 84. Georg Thieme, Leipzig 1927.

Klasens, H. A.: Measurement and calculation of unsharpness combinations in X-ray photography. Philips Research Reports Aug. 1946.

Polansky, D. and O'Connor, D. T.: X-Ray focal spot measurement. Non-destructive testing 12 (1954), 37.

Thorp, J. S.: Electron focussing in a demountable X-ray tube. J. Sci. Instr. 26 (1949), 201.

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THE DETERMINATION OF THE DISTRIBUTION OF INTERNALLY DEPOSITED THORIUM BY MEANS OF STUDIES WITH A REALISTIC PHANTOM

by

J. Rundo

The dosimetry of internally deposited radioactive isotopes has been much studied recently (MARINELLI, QUIMBY and HINE 1948; BUSH 1949; MAYNEORD 1950; MORGAN and FORD 1954) and methods of calculation of dose rate and integral dose are well established. However, all such calculations require a knowledge of the amount of the isotope and the size of the organ in which it is deposited; this is not always easy to obtain and different aspects of the problem have been studied by various workers (*e. g.* MITCHELL 1951; WALTON and SINCLAIR 1952; MITCHELL 1955).

The phantom used in the present investigation was specially designed to develop techniques for the determination of the thorium contents of liver and spleen of patients who had been injected intravenously with a colloidal suspension of thorium dioxide. Some preliminary results on the determination of the total burden from measurements of the total-body radioactivity have been reported elsewhere (RUNDO and FABER 1955).

Design and construction of the phantom. The previous studies which have been made with phantoms have been largely concerned with depth dose measurements from roentgen rays (*e. g.* MAYNEORD and CLARKSON 1944) of fairly low energy, and neutrons (MILLS and HURST 1954; BARR and HURST 1954). For soft roentgen rays, the effective atomic number of the phantom material is of great importance because of the variations in the energy absorption in tissues of different types (muscle, fat, bone) (SPIERS 1946, 1949, 1951; MUNSON 1950). For the interpretation of

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Fig. 1. The complete model lying on the patient couch.

external measurements of high-energy γ-rays from isotopes deposited within the body, the atomic number is of much less importance and water can be used with very little loss of accuracy. Of greater significance are the shapes and sizes of the organs containing the isotopes, and the presence of material which influences the scattering of the γ-rays (bones, air in the lungs, etc.).

From considerations such as these it was decided to build a phantom which resembled a 'standard man' and to incorporate in it models of liver and spleen (the organs containing the major deposits of thorium) and the lungs, as well as a skeleton. The model was built in five parts: head, 'thorax' (from the neck to the 1st lumbar vertebra), 'abdomen' (to just above the knees), and two legs. The thorax and abdomen were moulded in 4 mm acrylic sheet (Perspex) over a tailor's dummy, and the pieces joined together with Perspex cement. The bottom of the thorax and the top of the abdomen were made of sheets of plastic screwed into the sides, and the joints were made water-tight with thin rubber gaskets and vaseline. As these two parts were rather large no arms were made. The head and legs were also of acrylic plastic, and were of the type used in window dressing. The head was cut in two, a skull placed inside and the two halves cemented together. For filling purposes, a 10 mm hole was drilled in the neck in about the same position as the site of injection in most of the patients (common carotid artery).

No bones were included in the legs, as these were so remote from the deposits of activity as to have no effect on scattered radiation.

The models of liver, spleen and lungs were made by moulding 2.5 mm Perspex sheet over plaster of Paris models. The lungs were filled with 500 g each of sponge rubber and were sealed. The liver and spleen were fitted into the thorax with short pieces of polyvinyl chloride tubing so that they could be filled and emptied.

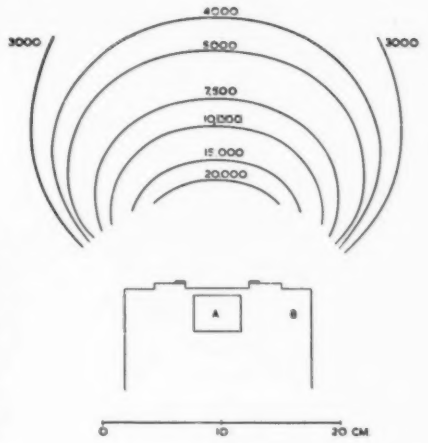

Diagram 1. Directional properties of the clinical scintillation γ-ray counter. The curves give the counting-rates shown (in counts per minute) from a 1 μc radium needle, the radiation being filtered by 1 mm lead placed in front of the crystal. Scaler bias 10V; photomultiplier E. H. T. 1,250V. A — NaI (Tl) crystal, 4 cm diameter, 3 cm thick. B — lead shielding.

The complete model (Fig. 1) is 175 cm long and weighs 70.35 kg distributed in the following way:

Weights of the five parts of the phantom

	Weight	
	Empty, kg	Filled with water, kg
Head	0.96	4.02
'Thorax'	5.70	27.00
'Abdomen'	4.38	31.80
Legs	0.95	7.53
Totals	11.99	70.35

Application. It is known that apart from occasional large deposits in the neck the greatest thorium deposits are in the liver and spleen with small deposits in the retroperitoneal lymph nodes. With known amounts of thorium in the liver and spleen of the phantom it should be possible to evaluate the distribution in these organs by external measurements. These results can then be applied to *in vivo* measurements.

Three factors must be taken into account in interpreting the counting-rates obtained from γ-ray measurements of phantom and patients. The directional properties of the counter were investigated with a 1 μc radium needle, and Diagram 1 shows that they are rather poor. Secondly, the shape and size of the liver and spleen are relevant, and finally, one of the most important γ-rays emitted by the decay-products of thorium is the 2.62 MeV quantum from ThC'' and this suffers only slight absorption in body tissues. These factors make it impossible to count the activity from one organ of major deposition without counting a contribution from the other.

The contributions of thorium deposits in liver and spleen of the phantom to the ionisation currents in a total-body γ-monitor (Rundo, a, 1955) have also been studied, and used to derive a theoretical ionisation current for the patients, due allowances being made for contributions to the current from the decay-products in the blood and the potassium in the body. These calculated currents have been compared with the measured values.

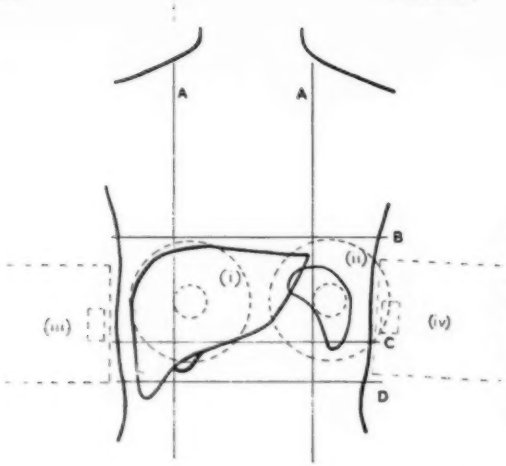

Fig. 2. Thorax and upper abdomen, showing the positions used for measuring the γ-ray activity from liver and spleen. AA — Mid-clavicular lines. B — inferior transverse line of thorax. C — transpyloric plane. D — infracostal line.
Counter positions: (i) liver, front; (ii) spleen, front; (iii) liver, side; (iv) spleen, side.

The activity in the liver-spleen regions of the patients and the phantom has been measured with the γ-ray counter (WARD and JENSEN 1952) in four standard positions, as indicated in Fig. 2. For convenience these positions have been called (i) liver, front, (ii) spleen, front, (iii) liver, side and (iv) spleen, side.

The size of the spleen of man varies from 0.17 per cent to 0.33 per cent of body weight for different age groups of both sexes (KROGMAN 1941). However, there is a tendency for the spleen to shrink with time and to be smaller than normal in cases of thorium dioxide poisoning (JOHANSEN, personal communication; THOMAS, HENRY and KAPLAN 1951). Spleens of two different sizes have therefore been used. The spleen built into the model held 47 g water, and a second set of measurements was made with a Foley catheter in place containing 53 g water, so that the total effective weight was 100 g.

Two factors complicate the interpretation of the results. The activity of the decay products of thorium varies with time and a correction for this must be made by the use of the γ-age-factor, F_γ. This is defined as the fraction of the equilibrium γ-ray activity which the thorium and its decay products have at any time (RUNDO and FABER 1955). In the phantom measurements, some thorium was used which at that time had a γ-age-factor of 0.437; this was determined by comparison of the specific activity with that of some thorium which had been analysed for *MsTh*$_1$ and *RdTh* (the two longest-lived daughter-products of thorium) so that the γ-age-factor could be calculated at any time.

An important complication arises as a result of wash-out of some of the decay-products by the blood-stream. To correct for this a washout-factor is defined:

$$F_w = \frac{\text{theoretical } \gamma\text{-ray activity for age-factor } F_\gamma \text{ (no washout)}}{\text{actual } \gamma\text{-ray activity for age-factor } F_\gamma \text{ (with washout)}}$$

In principle, F_w can be determined from a study of the long-term behaviour of the γ-ray activity of a biopsy or autopsy specimen and analysis of the activity-time curves, but no acceptable material was available. The alternative procedure of comparing the measured activities of the patients in the total-body γ-monitor with the measured activity of thorium of known γ-age-factor in the phantom seemed more promising, and the procedure described below was adopted. The amounts of thorium present in liver and spleen are calculated by multiplying the activities by $\frac{0.437\ F_w}{F_\gamma}$, where F_γ corresponds to the age of the thorium in the patient at the time of the measurements.

Treatment of experimental measurements. From the measurements with the phantom we can set up simultaneous equations, relating the measured activities to the amounts of thorium present in liver and spleen. Let the counting rates in the four positions be (i) $C_{L(F)}$, (ii) $C_{S(F)}$, (iii) $C_{L(S)}$ and (iv) $C_{S(S)}$. Then for the particular counter used here

$$C_{L(F)} = 940L + 90S \quad \ldots\ldots\ldots\ldots 1$$
$$C_{S(F)} = 209L + 540S \quad \ldots\ldots\ldots\ldots 2$$
$$C_{L(S)} = 1{,}172L + 120S \quad \ldots\ldots\ldots\ldots 3$$
$$C_{S(S)} = 250L + 3\,800S \quad \ldots\ldots\ldots\ldots 4$$

where L and S are the contents of the organs in equivalent grams of the thorium used for the calibration measurements (referred to as 1949 thorium, the year it was received at the laboratory) and the figures are the measured contributions to the counting rates per gram of 1949 thorium in the appropriate organ, under the same counting conditions (E. H. T., scaler bias, filtration) as used for patient observations. The contributions to the counting rates from the thorium in the spleen in these equations are those measured with the 47 g spleen. For the 100 g spleen the equations become

$$C_{L(F)} = 940L + 143S \quad \ldots\ldots\ldots\ldots 1\,a$$
$$C_{S(F)} = 209L + 860S \quad \ldots\ldots\ldots\ldots 2\,a$$
$$C_{L(S)} = 1{,}172L + 138S \quad \ldots\ldots\ldots\ldots 3\,a$$
$$C_{S(S)} = 250L + 2{,}460S \quad \ldots\ldots\ldots\ldots 4\,a$$

The two equations which are likely to give the 'best' values for L and S are those for $C_{L(S)}$ and $C_{S(S)}$. Slight changes in the lateral position of the counter may cause quite large changes in the relative contributions from liver and spleen to $C_{L(F)}$ and $C_{S(F)}$ without much change in their sum. On the other hand, slight changes in the counter position will not affect the contributions to $C_{L(S)}$ and $C_{S(S)}$ very much because the spleen presents a larger area to the counter window, when seen from these projections. Further, when measuring $C_{L(S)}$ the major contribution to the activity is from L with only a small contribution from S, and vice versa for $C_{S(S)}$. The variations in absolute sizes of liver and spleen and their distances apart will introduce an uncertainty in the measurements on patients.

Determination of F_w. The values of L and S are converted into grams of thorium present in liver and spleen by multiplying by $\frac{0.437\ F_w}{F_\gamma}$; F_γ follows at once from the time elapsed between injection and measurement, but the value of F_w is a little more obscure. The data on 49 patients for whom the injected dose was recorded unambiguously, who had no neck deposits, and whose blood activity had been measured, were chosen for its determination.

The ionisation currents produced in the total-body apparatus by the potassium contents of the patients of 0.21 % and 0.18 % of body weight for males and females respectively (Rundo, a, 1955; Rundo and Sagild 1955) were calculated and subtracted from the measured currents.

The contribution to the current from the activity in the blood was then calculated. This activity is due to *ThB* and *ThX*; the β-activity was measured in a liquid counter, and to determine the contribution from the potassium in the blood a mean value was obtained by β-counting blood from several control patients. This value was subtracted from the measured activities of the blood of the thorium patients, and the total activity for the whole of the patient's blood was calculated assuming 85 ml blood per kg body weight (Sunderman and Boerner 1949). The contribution of this activity to the ionisation current was calculated from a calibration measurement in the total-body apparatus

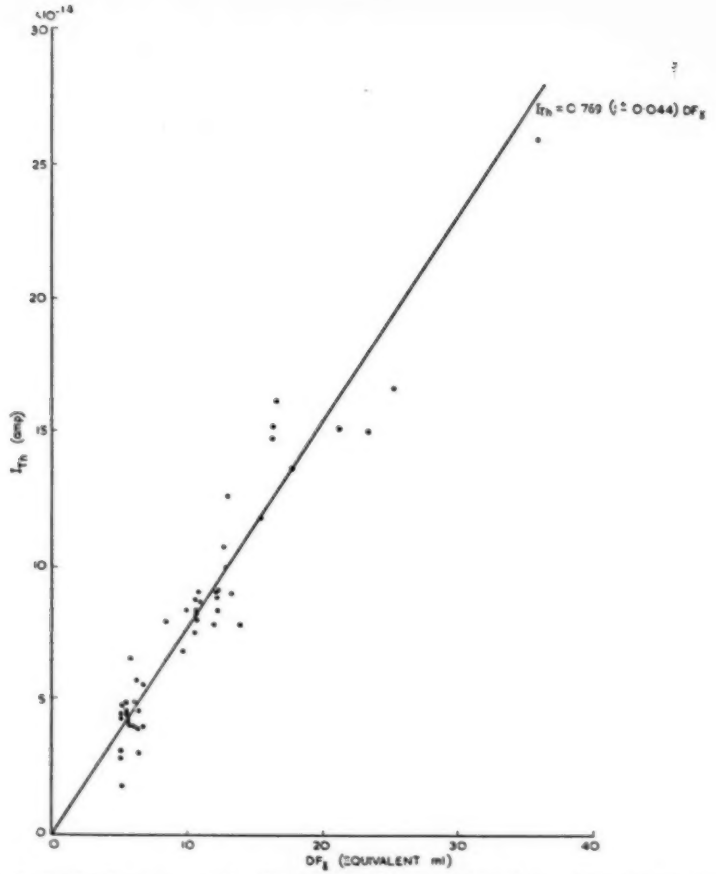

Diagram 2. Ionisation current in the total-body γ-monitor from 49 patients, corrected for contributions from ^{40}K and activity in the blood, as a function of DF_γ, the product of the injected volume of colloidal thorium dioxide and the γ-age factor.

of a solution of *ThB* both as a small source and distributed throughout the phantom, and measurement of the β-activity of an aliquot. Due allowance was made for the distribution in the body (assumed uniform), and the final current was subtracted from that corrected for potassium. The remainder, I_{Th}, represents the contribution to the measured current from the thorium deposits in liver and spleen together with small amounts in other sites, which are estimated at not more than about 10 per cent. The values of I_{Th} were plotted as a function of DF_γ, the product of injected volume of colloidal thorium dioxide and γ-age-factor (Diagram 2). A least-squares treatment of the data yielded the relation

$$I_{Th} = 0.769\ (1 \pm 0.044) DF_\gamma$$

when I_{Th} is expressed in units of 10^{-14} *A* and DF_γ in equivalent ml. (1 ml colloidal thorium dioxide contains 0.20 g thorium.)

For the currents given by the phantom two possibilities of distribution between liver and spleen must be considered, referring to the two sizes of spleen used. For the 47 g spleen, the mean of the calculated ratio L/S (determined from equations 3 and 4) for 15 patients was 8.72, while for the 100 g spleen it was 4.26 (determined from equations 3a and 4a). The currents given by thorium deposited in the phantom liver and spleen were calculated for these two ratios giving

$$I_{Th}' = 2.164\ (1 \pm 0.017) DF_\gamma \quad \text{for the 47 g spleen}$$

and $$I_{Th}'' = 2.260\ (1 \pm 0.015) DF_\gamma \quad \text{for the 100 g spleen.}$$

Thus we have two theoretical values for F_w, depending on the size of the spleen:

$$F_w = \frac{2.164\ (1 \pm 0.017)}{0.769\ (1 \pm 0.044)} = 2.81 \pm 0.13$$

or

$$F_w = \frac{2.260\ (1 \pm 0.015)}{0.769\ (1 \pm 0.044)} = 2.94 \pm 0.14$$

From these figures it is seen that there is no significant difference between the two. All the errors in the above are standard errors.

The values of F_w calculated in this way are lower ($\gg$ 10 %) than the true values, as the numerator of the fraction represents the current from the phantom with thorium in the liver and spleen only, while the denominator represents the current from the patients with thorium in other sites as well. The amounts of thorium calculated with the aid of F_w will also be under-estimated slightly.

Neck deposits. Using the technique developed by the author (Rundo 1956) for the localisation of a point source embedded in an absorbing medium, those cases with single-sided paravasal deposits of thorium in the neck can be studied. After the depth of the source in the tissue has been determined, the counting-rate is corrected for scatter by reference to measurements of thorium sources at various depths in water. From the known sensitivity of the counter to a point source, this corrected counting rate is converted to N, the content of the neck deposit in equivalent grams of 1949 thorium, and this is further converted to grams of thorium present by means of the γ-age-factor. The washout factor has been measured in the case of a small biopsy sample from the neck deposit of one patient and found to be 1.0, within experimental error. This seems to be due to the avascular nature of the connective tissue, in contrast to liver and spleen. Thus, the absolute amount of thorium in the neck is given by $0.437\ N/F_\gamma$. The phantom is used to determine the contribution to the ionisation current in the total-body γ-monitor from the neck deposit, again using 1949 thorium.

Results

The choice of the equations for $C_{L(S)}$ and $C_{S(S)}$ and the values of F_w for determining the thorium contents of the organs can only be justified when such organs become available for chemical analysis following operation or death. Three patients were splenectomised after external γ-ray measurements had been made; one of these patients died about three years later and the liver content was determined. A fourth patient died, and spleen and liver were analysed for thorium. The results are shown in Table 1; the γ-ray counter used for the measurements on patients 2, 87 and 363 was of lower sensitivity than that used for patient 160 and for the phantom measurements. While a correction could be made for this, it was not possible to allow for the differences in direc-

Table 1

Results for four patients for whom analytical data were available

Patient number and sex	Calculated thorium content of spleen g	Calculated thorium content of liver g	Actual thorium content of spleen g	Actual thorium content of liver g
2 F	1.94—4.29	8.76—19.35	2.5	*
87 M	1.37	2.14	1.8	*
160 F	0.47	2.45	0.75—1.92	2.0—2.4
363 M	1.0	2.83	0.75**	2.6

* Patient living.
** Not including content of accessory spleen.

tional properties and this should be borne in mind when assessing the results. In general, the agreement between the thorium contents calculated from the counter measurements and those from the analyses is satisfactory. In the case of patient 2, the measurements were made 4.2 years after the injection, and after such a short period the initial isotopic composition of the thorium is of great significance, so that the γ-age-factor must be quoted within wide limits (RUNDO, b, 1955). The amounts of thorium present can only be calculated within corresponding limits. The limits shown for the contents of spleen and liver of patient 160 arise as a result of wide variations in the thorium concentrations in the samples of tissue taken for analysis.

This patient also had a double-sided neck deposit. Measurements of its activity could not be treated rigorously, but examination of a radiograph of the neck indicated that the centres of the deposits were both about 3 cm under the skin and 9 cm apart. With the centre of the NaI(Tl) crystal 6 cm from the skin, measurements of the activity were made from opposite sides of the neck and the contents of the two deposits were then calculated. They were 0.95 and 1.27 g thorium for left and right sides respectively, so that the total in liver, spleen and neck was 5.14 g corresponding to 26 ml of colloidal thorium dioxide.

The weights of the spleens of the four patients were 100, 47, 17.5 and 335 g respectively; the results in Table 1 were calculated using the results from the measurements with the appropriate phantom spleen (small or large). In calculating the thorium contents for living patients the unknown spleen size introduces a possible error, but a radiograph of the spleen can give an indication of the size and hence which pair of equations to use.

It seems established that the method of calculating the thorium burdens in liver and spleen is sufficiently reliable even though it is based on a highly idealised phantom. It must, however, be emphasized that the results are not precision determinations and they cannot reasonably

Table 2

Calculated distribution of thorium in 15 patients

Patient number	Calculated thorium content of liver g	of spleen g	of neck g	Total g	Fraction of injected amount of thorium found
73	1.37	0.13	0.36	1.86	0.93
86	5.54	0.46	0.09	6.09	1.01
140	2.78	0.74	—	3.52	0.88
238	5.19	1.69	—	6.88	0.86
366	1.79	0.36	0.51	2.66	?*
416	2.68	0.51	—	3.19	0.80
441	1.79	0.98	0.56	3.33	?*
456	2.72	0.75	—	3.47	0.96
484	1.04	0.78	0.67	2.49	?*
592	2.08	0.61	—	2.69	0.67
626	3.29	0.40	—	3.69	0.92
639	2.53	0.31	—	2.84	0.94
652	1.29—1.75	0.52—0.71	0.14	1.95—2.60	?*
670	4.25	0.82	?**	> 5.07	?*
724	3.10	2.03	—	5.13	?*

* Amount injected not recorded.
** Double sided neck deposit, not susceptible of accurate calculation.

be expected to give better accuracy than about $\pm$ 20 %. An important effect which contributes to the accuracy is the assumption that F_w, determined from measurements of the total-body γ-ray activity, has the same value for liver and spleen. From studies of the build-up of the activities of liver and spleen tissue samples from rabbits and patients it is known that the washout factor is slightly lower for liver than for spleen, but the difference is not great (about 10 %), and is not important to the general argument.

Calculated ionisation current. From the thorium contents in equivalent grams of 1949 thorium of liver, spleen and neck deposits, the ionization current in the total-body γ-monitor can be calculated as

$I_{calc}' = (3.78S + 4.84L + 5.61N) \times 10^{-14} + I_B + I_K$ amp, for the results calculated from the 47 g spleen measurements, or

$I_{calc}'' = (5.35S + 4.84L + 5.61N) \times 10^{-14} + I_B + I_K$ amp, for the results calculated from the 100 g spleen measurements, where

S, L and N are as already defined,

I_B is the ionisation current from the activity in the blood,

I_K is the ionisation current from the potassium content of the patient, and the coefficients of S, L and N are the currents (in units of 10^{-14} amp) given by 1 g deposits of 1949 thorium in the spleen, liver and neck respectively, of the phantom.

These values of the calculated ionisation current take no account of contributions to the current from thorium deposits in other sites, nor from small amounts of $MsTh_1$ and ThX (the radium isotopes) taken up by the skeleton from the blood stream, and they should therefore be somewhat lower than the measured values.

Discussion

The results obtained from measurements on patients may now be considered. Calculations have been made along the lines indicated above for 15 patients. In six cases, the amount injected was not recorded in the case history. The time between injection and the measurements was in the range 6.2 to 18.6 years; in the case of the shortest time intervals, there was an uncertainty in the value of $F\gamma$ but this was only significant in one case (patient 652). The amounts injected were from 10 to 40 ml colloidal thorium dioxide, containing from 2 to 8 g thorium.

For each patient, the thorium contents of liver and spleen were calculated using equations 3 and 4 (47 g phantom spleen) and 3a and 4a (100 g phantom spleen), and the ionisation current in the total-body apparatus was also calculated for both possibilities. Inspection of the results showed that the assumption of a small spleen could only be

Table 3

Calculated and observed total-body activity from 15 patients

Patient Number	Calculated ionisation current* in total-body γ-monitor from thorium	from ^{40}K	from activity in blood	Total	Measured ionisation current* in total-body γ-monitor
73	7.82	0.87	0.43	9.12	13.6 ± 0.6
86	18.84	0.92	2.98	22.74	18.5 ± 0.6
140	9.94	0.75	**	> 10.69	15.4 ± 0.5
238	17.47	0.74	**	> 18.21	22.9 ± 0.5
366	9.76	0.57	**	> 10.33	14.3 ± 0.5
416	7.45	0.86	1.04	9.35	10.0 ± 0.6
441	11.06	0.74	0.96	12.76	16.8 ± 0.3
456	8.09	0.86	0.77	9.72	10.2 ± 0.6
484	9.70	0.77	0.74	11.21	16.1 ± 0.6
592	5.73	0.83	**	> 6.56	8.8 ± 0.3
626	6.77	0.63	**	> 7.40	8.7 ± 0.3
639	4.98	0.74	**	> 5.72	7.4 ± 0.3
652	4.32—5.59	0.89	0.58	5.79—7.06	8.6 ± 0.6
670	> 9.20	1.06	1.24	> 11.50	14.5 ± 0.6
724	8.20	0.73	**	> 8.93	10.7 ± 0.5

* Current in units of 10^{-14} amp.
** Blood activity not measured.

Table 4

Results for six patients with unknown injection data

Patient number	Estimated amount injected		Calculated thorium content	Recovery
	ml	g	g	
366	15	3	2.66	0.89
441	20	4	3.33	0.83
484	12	2.4	2.49	1.04
652	15	3	1.95—2.60	0.65—0.87
670	30	6	> 5.07	> 0.84
724	25	5	5.13	1.03

justified for two patients, both on the basis of recovery of thorium and of calculated total-body activity. These two patients (73 and 86) were injected 16.5 and 18.6 years prior to the measurements, which was longer than for the other patients. This seems to indicate a shrinkage of the spleen, in agreement with the findings in one case of THOMAS et al. (1951).

In Table 2 are set out the results of the determinations of the distribution of the thorium, and in Table 3 the results of calculations of the total-body radioactivity may be compared with the measured values. It is clear that in nearly every case the total activity of the deposits is almost completely accounted for, and in the nine cases where the amount injected has been recorded, the weight of thorium calculated indicates good recovery. This is significant of the very slight excretion of the deposits of thorium even after nearly 20 years. Further it must be remembered that the amount quoted as having been injected was not an accurate measurement and it is perhaps surprising to find such good agreement.

The six cases where the injected volume was not recorded may be considered in the light of estimates of this quantity, based on local and generalised γ-activity measurements of the body, on blood activity measurements and on activity in the exhaled breath, but without reference to phantom studies (RUNDO and FABER 1955). The appropriate data are set out in Table 4 and from these it is seen that "recoveries" of about the same size are obtained as in the other nine cases. We now attempt to estimate the amount of thorium in sites other than liver, spleen and neck by considering the discrepancies (a) between the amount of thorium calculated and that quoted as having been injected, and (b) between the calculated and measured ionisation currents in the total body γ-monitor. Although it is not possible to make an estimate of this amount for each patient individually, we can derive an average for a group of patients.

The results for patients 73, 86, 416, 441, 456, 484 and 652 may be considered. For these seven patients the mean of the recoveries of the

injected amount of thorium is 0.87, while the mean of the ratios $\frac{I_{calc}}{I_{meas}}$ is 0.86. These seven patients are those whose blood activity had been measured; we may extend the comparison to include those patients whose blood activity was not measured, if we make an estimate of the contribution to the ionisation current from the blood activity. The mean of the ratios

$$\frac{\text{Calculated ionisation current from blood activity}}{\text{Calculated ionisation current from thorium only}}$$

for the seven patients listed above is 0.10. Hence, a reasonable estimate for the ionisation current from the blood activity of patients 140, 238, 366, 592, 626, 639 and 724 is 10 per cent of the calculated currents from the thorium alone (column 2 of Table 3). In this way we find that the mean of the ratios $\frac{I_{calc}}{I_{meas}}$ for 14 patients is 0.85. For the same 14 patients the mean recovery of thorium is 0.88. As indicated above this is a slight under-estimate, as is the calculated ionisation current, the latter having an additional source of error. The conclusion seems to be that at most 10 to 12 per cent of the thorium is present in sites in the body other than the liver and spleen, and the major part of this is likely to be in the red bone-marrow.

The data obtained by LOONEY et al. (1956) suggest that in the first few months following injection, the excretion rate of the thorium corresponds to a biological half-life in excess of 190 years. If this excretion rate be maintained, the retention at 12 years (the mean period for the 15 patients considered here) would be 96 %, the range of 6.2 to 18.6 years corresponding to a range in retention of 98 % to 93 %. However, there is evidence in the results of LOONEY et al. and also from studies made in this Institute that the excretion rate is reduced with time, so that the retentions would be higher than indicated here.

Finally, we may summarise the distribution of the thorium between liver, spleen and other sites. For this purpose we ignore the five cases with neck deposits greater than 0.1 g of thorium, as well as patient number 670 (neck deposit of unknown size). For the remaining nine patients, the mean liver content is 0.71 of the total thorium injected, and the mean spleen content is 0.17. Of the remainder, 0.12 of the amount injected, the major part is likely to be in the red bone-marrow. We conclude that although little significance should be attached to the second decimal quoted in the results, fairly reliable calculations of dose-rate and cumulative dose may be made, as described elsewhere (RUNDO, b, 1955). Such calculations are of value in assessing radiation damage and interpreting the clinical picture.

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SUMMARY

A full-size realistic phantom 'man' is described; it is made in Perspex, and filled with water. Models of the lungs, liver and spleen, and a skeleton are incorporated. Measurements of the gamma-radiation from known amounts of thorium in the liver and spleen of the phantom enable estimates to be made of the thorium contents of liver and spleen of patients, years after intravenous injection with colloidal thorium dioxide, solely from external gamma-ray measurements. The results are shown to be in good agreement with the amounts recorded at the time of injection, or with the amounts estimated on the basis of measurements of radioactivity without reference to phantom studies. Thorium deposits occasionally found at the site of the injection (common carotid artery) have also been studied, and the results of measurements can be interpreted in terms of the amounts present. The amount of thorium in the red bone-marrow is discussed in the light of the amounts found elsewhere.

ZUSAMMENFASSUNG

Ein realistisches Phantom 'Mensch' in Erwachsenengrösse wird beschrieben; es ist aus Perspex hergestellt und mit Wasser gefüllt. Modelle der Lungen, der Leber, der Milz und ein Knochengerüst sind eingebaut. Messungen der Gammastrahlung bekannter Mengen von Thorium in Leber und Milz des Phantomes ermöglichen es, den Thoriumgehalt der Leber und Milz von Patienten, jahrelang nach der Injektion von kolloidalem Thoriumdioxid, ausschliesslich auf Grund der externen Gammastrahlenmessungen zu beurteilen. Die Ergebnisse sind in guter Übereinstimmung mit den im Injektionsaugenblick registrierten Mengen, oder mit den Beträgen, welche auf Grund von Radioaktivitätsmessungen ohne Berücksichtigung von Phantomstudien geschätzt wurden. Gelegentlich an der Injektionsstelle (A. carotis communis) gefundene Thoriumdepositionen sind ebenfalls studiert worden und die Resultate können nach den vorhandenen Mengen beurteilt werden. Die Thoriummengen im roten Knochenmark wird im Lichte der an anderen Körperstellen gefundenen Mengen diskutiert.

RÉSUMÉ

L'auteur décrit un 'homme' fantôme, ressemblant et en vraie grandeur, fait en Perspex et rempli d'eau. Des modèles de poumons, de foie et de rate et un squelette y sont incorporés. Des mesures du rayonnement gamma émis par une quantité connue de thorium contenue dans le foie et la rate du fantôme permettent d'estimer, d'après les seules mesures externes du rayonnement gamma, des années après injection intraveineuse de dioxyde colloïdal de thorium, le contenu en thorium du foie et de la rate des malades. Les résultats sont en bon accord avec les quantités notées au moment de l'injection, ou avec les estimations fondées sur des mesures de radioactivité faites sans recourir aux études sur fantôme. Les 'thorotrastomes' découverts parfois au lieu d'injection (artère carotide primitive) ont aussi été étudiés, et les résultats des mesures peuvent être interprétés comme en rapport avec les quantités présentes. La quantité de thorium contenue dans la moëlle rouge des os est étudiée en fonction des quantités trouvées ailleurs.

REFERENCES

BARR, T. A. and HURST, G. S.: Fast-neutron dose in a large tissue-equivalent phantom. Nucleonics 12 (1954): 8, 33.

BUSH, F.: The integral dose received from a uniformly distributed radioactive isotope. Brit. J. Radiol. 22 (1949), 96.

KROGMAN, W. M.: Tabulae Biologicae, Vol. 20, p. 676. Groetschel and v. Assema Metz, the Hague 1948.

LOONEY, W. B., HURSH, J. B., ARCHER, V. E., STEADMAN, L. T. and COLODZIN, M.: A summary of radium and thorium excretion in humans. Proc. Intern. Conference on Peaceful Uses of Atomic Energy 11 (1956), 55.

MARINELLI, L. D., QUIMBY, E. H., and HINE, G. J.: Dosage determination with radioactive isotopes. II. Practical considerations in therapy and protection. Am. J. Roentgenol. 59 (1948), 260.

MAYNEORD, W. V.: Some Applications of Nuclear Physics to Medicine. Brit. J. Radiol. Suppl. 2 (1950).

— and CLARKSON, J. R.: Energy absorption. II. Integral dose when the whole body is irradiated. Brit. J. Radiol. 17 (1944), 151.

MILLS, W. A. and HURST, G. S.: Fast-neutron dosimetry in a small tissue-equivalent phantom. Nucleonics 12 (1954): 4, 17.

MITCHELL, J. S.: Practical aspects of radioactive isotopes in relation to medical treatment. Brit. med. J. 2 (1951), 747.

— Chapter in British Practice in Radiotherapy p. 97. Butterworths Medical Publications, London 1955.

MORGAN, K. Z. and FORD, M. R.: Developments in internal dose determinations. Nucleonics 12 (1954): 6, 32.

MUNSON, R. J.: Note on the paper by F. W. Spiers entitled 'The influence of energy absorption and electron range on dosage in irradiated bone.' Brit. J. Radiol. 23 (1950), 505.

RUNDO, J.: (a) An apparatus for the measurement of γ-radiation from the human body. J. Sci. Inst. 32 (1955), 379.

— (b) Considerations of the limits of radiation dosage from thorotrast. Brit. J. Radiol. 28 (1955), 615.

— The localisation of point sources of radioactivity in absorbing media. Brit. J. Radiol. 29 (1956), 352.

— and FABER, M.: Total-body γ-radiation from patients with internally deposited thorium. Rec. Trav. Chim. Pays-Bas. 74 (1955), 416.

— and SAGILD, U.: Total and 'exchangeable' potassium in humans. Nature 175 (1955), 774.

SPIERS, F. W.: Effective atomic number and energy absorption in tissues. Brit. J. Radiol. 19 (1946), 52.

— The influence of energy absorption and electron range on dosage in irradiated bone. Brit. J. Radiol. 22 (1949), 521.

— Dosage in irradiated soft tissue and bone. Brit. J. Radiol. 24 (1951), 365.

SUNDERMAN, F. N. and BOERNER, F.: Normal Values in Clinical Medicine, p. 172. W. B. Saunders Co., Philadelphia 1949.

THOMAS, S. E., HENRY, G. W. and KAPLAN, H. S.: Hepatolienography: past, present and future. Radiology 57 (1951), 669.

WALTON, R. J., and SINCLAIR, W. K.: Intracavitary irradiation with radioactive colloidal gold in the palliative treatment of malignant pleural and peritoneal effusions. Brit. Med. Bull. 8 (1952), 165.

WARD, A. H., and JENSEN, P. G.: A crystal-photomultiplier gamma counter for hospital use. J. Sci. Inst. 29 (1952), 181.

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THE EFFECTS OF A HIGH EXPLOSIVE BLAST IN MICE WITH RADIATION INJURY

by

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Clinical as well as experimental data give supporting evidence to the statement that hemorrhagic diathesis is one of the most prominent features of severe radiation injury (ALLEN et coll. 1951). In fact, hemorrhages in skin and various internal organs were reported to be a constant finding in those Japanese atom bomb victims who were classified as having sustained severe radiation injury (CRONKITE et coll. 1952).

As the cause of the hemorrhagic state at least three different radiation-induced pathologic changes have been discussed, viz. 1) a consistent thrombocytopenia and a reduced clot retraction, 2) an increase of the bleeding and clotting time, and 3) an increased capillary fragility. Although the effects of ionizing radiation on the capillaries are still incompletely known, the injury to the capillary system is supposed by some authors (cf. ARONS et coll. 1954) to be the primary cause of the tissue damage caused by irradiation. In some way or other, the integrity of the capillary wall is broken, and SOKOLOFF and co-workers (1950) state that the hemorrhages are due to an increased capillary fragility and not to an increased permeability of the walls of the vessels.

A detonation of nuclear weapons will, in addition to the radiation damage, also be likely to cause blast injuries in a fraction of the exposed individuals. As has been shown by a number of authors (see *e. g.* HOOKER 1924, ZUCKERMAN 1940, 1941, CLEMEDSON 1949) the most constant autopsy finding in blast injury is hemorrhages in the lungs due to the blast effect on the lung capillaries, which are rather poorly supported by surrounding tissue. The hemorrhages vary in different cases from superficial petechiasis to total hepatization of whole lobes or lungs.

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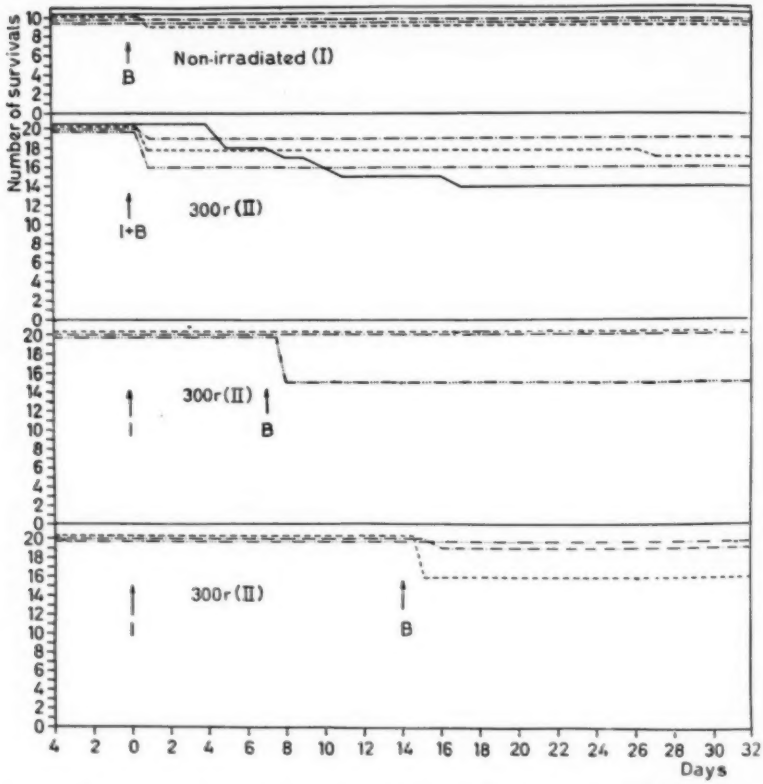

Diagram 1. Number of survivals. Group A (no blast). Group B, E, H (blast pressure 4.0 kp/cm²) – – –. Group C, F, I (blast pressure 5.5 kp/cm²) – · –. Group D, G, J (blast pressure 6.7 kp/cm²) – · · · – (See also Table 1.)
I = irradiation; B = blast exposure.

The main factors that determine the extent of lung injury caused by the blast are regarded to be the maximum pressure and impulse of the detonation and the resistance of the pulmonary capillaries. The lung damaging effects of detonations of different pressures and impulses have been tested in a great number of experiments by CLEMEDSON (1949), among others. The resistance of the pulmonary capillaries, on the other hand, has been given much less attention, possibly due to the difficulty of an experimental variation of that factor at will. An irradiation with different doses, however, would probably provide such a possibility.

Studies on the combined effects of whole body irradiation and blast

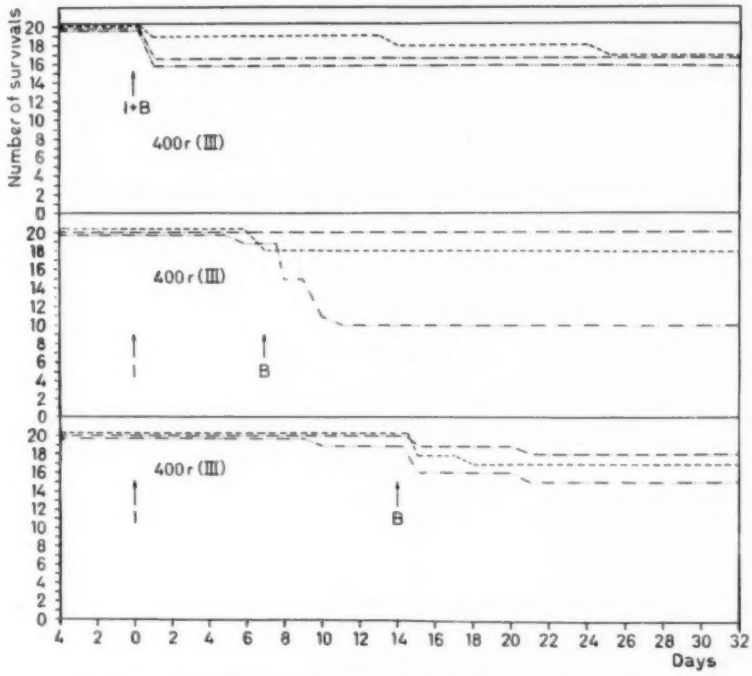

Diagram 2. Number of survivals. Symbols as in diagram 1.

injury in mice have been made by CASSEN and co-workers (1950, 1953) and by CLEMEDSON and NELSON (1955). If mice irradiated with an approximate LD_{50} dose (about 600 r) were blasted at various times after irradiation (CASSEN, CURTIS, and KISTLER 1950), the average hemorrhage scores for all groups did not significantly differ from those of the control groups. In a recent paper, however, CASSEN and KISTLER (1953) report a considerably higher degree of pulmonary edema in radiation-weakened mice than in the non-irradiated controls.

In a previous investigation CLEMEDSON and NELSON (1955) found no significant increase of mortality in groups of mice exposed on the same day to various doses of roentgen irradiation and to blast waves of different maximum pressures. As this could be due to the fact that the pulmonary capillary fragility would take about one week to develop (CASSEN and KISTLER 1954), the present investigation was undertaken to study the effects of a high explosive blast in radiation-injured animals.

Material and methods. Six hundred and thirty (630) white male mice of our own pure breed, and weighing about 21 g each, were used for this inves-

tigation. They were grouped in twenties, except in the control experiments where only groups of ten were used. The animals were exposed to roentgen radiation in the following doses: 300 r, 400 r, and 500 r. The irradiation data were: 250 kV, 10 mA, 4 mm Al + 0.5 mm Cu and F.T.D. 40 cm. The dose rate was 116 r/min.

The irradiated animals were exposed to a high explosive blast and followed up in the same way as described in a previous paper (CLEMEDSON and NELSON 1955).

Groups of animals were exposed to the blast, one third on the day of irradiation, one third 7 days afterwards, and one third 14 days afterwards, according to the experimental conditions tabulated below.

Experimental conditions

Group	Irradiation dose in r	Blast on irradiation day Max. blast pressure*) kp/cm²	Blast 7 days after irradiation Max. blast pressure*) kp/cm²	Blast 14 days after irradiation Max. blast pressure*) kp/cm²
I A	—	—	—	—
I B	—	4.0	—	—
I C	—	5.5	—	—
I D	—	6.7	—	—
II A	300 r	—	—	—
II B	»	4.0	—	—
II C	»	5.5	—	—
II D	»	6.7	—	—
II E	»	—	4.0	—
II F	»	—	5.5	—
II G	»	—	6.7	—
II H	»	—	—	4.0
II I	»	—	—	5.5
II J	»	—	—	6.7
III A	400 r	—	—	—
III B	»	4.0	—	—
III C	»	5.5	—	—
III D	»	6.7	—	—
III E	»	—	4.0	—
III F	»	—	5.5	—
III G	»	—	6.7	—
III H	»	—	—	4.0
III I	»	—	—	5.5
III J	»	—	—	6.7
IV A	500 r	—	—	—
IV B	—	4.0	—	—
IV C	—	5.5	—	—
IV D	—	6.7	—	—
IV E	—	—	4.0	—
IV F	—	—	5.5	—
IV G	—	—	6.7	—
IV H	—	—	—	4.0
IV I	—	—	—	5.5
IV J	—	—	—	6.7

*) The pressures are the maximum reflection overpressure.

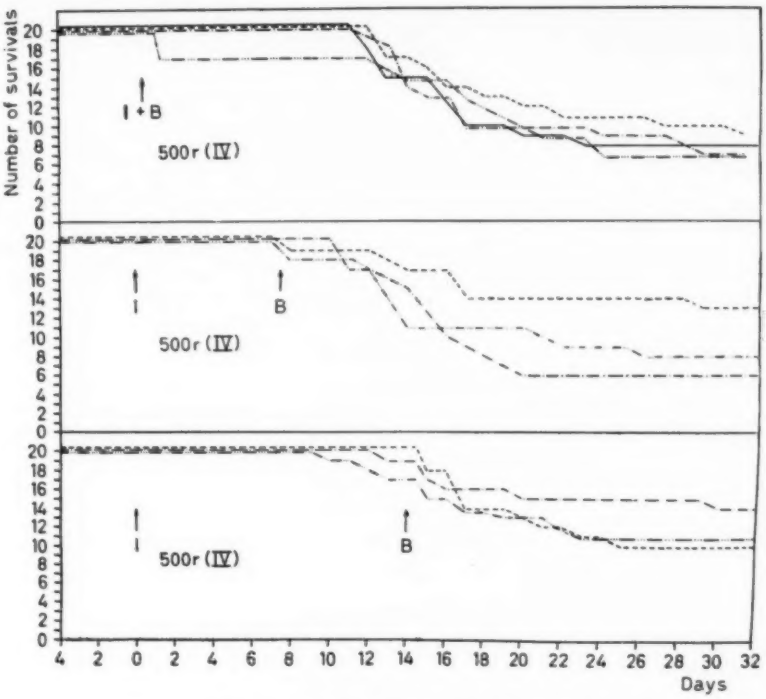

Diagram 3. Number of survivals. Symbols as in diagram 1.

In the animals which died during the observation period the lungs were removed and weighed in order to obtain a quantitative measurement of the extent of the lung hemorrhages. For details of the method the reader is referred to CLEMEDSON (1949).

Results

Diagram 1 shows the survivals in the non-irradiated groups and the groups irradiated with 300 r. Only a few deaths occur in the irradiated groups, and in all the blasted groups they appear in connection with the blast. In some cases, death was caused by metal fragments from the blasting cap. The highest number of deaths is found in the non-blasted groups.

Diagram 2 shows the number of survivals in the groups irradiated with 400 r. From the curves it will be seen that the majority of deaths occur in connection with the blast, independently of the time of blast,

and that the highest number of deaths occurred in the groups with the maximum blast pressure. In these groups, there were no signs of external injuries.

As no mice died in the non-blasted groups, the high mortality in the corresponding 300 r groups must be regarded as accidental.

Diagram 3 shows the survivals in the groups irradiated with 500 r. The mortality in the irradiated non-blasted group was about 50 per cent, and the survival time about 15 days. The same result will be seen also in the groups blasted on the day of irradiation and 7 days afterwards. In the groups blasted 14 days after the irradiation, the mortality is lower and the mean survival time slightly increased. The difference is, however, not statistically significant.

The examination of the lungs from the dead mice showed, at least in the animals which died in connection with the blast exposure, significantly increased weights due to hemorrhages. In the mice dying before the blast, or several days after the blast, the increase in lung weights was insignificant.

Conclusions

The present investigation has confirmed our previous work (Clemedson and Nelson 1955). The combination of blast and radiation injuries does not significantly increase the mortality in mice, in comparison with these injuries given separately. This is remarkably the case even if the blast is applied 7 days and 14 days after the irradiation, *i. e.* during the period of expected lowered resistance to infections and tendency to hemorrhages. Furthermore, this study has shown that the increase in blast pressure does not increase the mortality in the combined injuries, which also essentially confirms our earlier observations.

SUMMARY

Groups of irradiated mice were exposed to high explosive blast, on the day of irradiation, and, respectively, 7 days afterwards, and 14 days afterwards. The combination of blast and radiation injuries did not significantly affect the survival.

ZUSAMMENFASSUNG

Eine Gruppe bestrahlter Mäuse wurde der Einwirkung von explosivem Druckstoss ausgesetzt, und zwar am Tage der Bestrahlung, 7 Tage bezw. 14 Tage nachher. Die Kombination von Druckstoss und Bestrahlungsschädigung hat das Überleben nicht beträchtlich beeinflusst.

RÉSUMÉ

Des groupes de souris irradiées ont été exposés à un violent souffle d'explosion le jour même de l'irradiation et respectivement 7 jours et 14 jours après. La combinaison des lésions de souffle et d'irradiation n'a pas affecté la survie d'une manière significative.

REFERENCES

Allen, J. G., Moulder, P. V., and Enerson, D. M.: Pathogenesis and treatment of the post-irradiation syndrome. J.A.M.A. 145 (1951), 704.

Arons, I., Freeman, J., Sokoloff, B., and Eddy, W. H.: Bio-flavonoids in radiation injury. 1. The effect of ionizing radiation on capillaries. Brit. J. Radiol. 27 (1954), 583.

Cassen, B., Curtis, L., and Kistler, K.: Initial studies of the effect of laboratory-produced air blast on animals. J. Aviation Med. 21 (1950), 38.

— and Kistler, K.: Effect of mid-lethal whole body X-ray exposure of mice on the production of acute pulmonary edema by air blast injury. UCLA-266, 1953. Ref. in Nuclear Sc. Abstr. 7 (1953), 699.

— Development of acute pulmonary edema in mice and rats and an interpretation. Am. J. Physiol. 178 (1954), 49.

Clemedson, C.-J.: An experimental study on air blast injuries. Acta physiol. Scandinav. Suppl. 61 (1949).

— and Nelson, A.: Effects of combined whole body roentgen irradiation and high explosive blast injury in mice. Acta radiol. 43 (1955), 161.

Cronkite, E. P., Jacobs, G. J., Brecher, G., and Dillard, G.: The hemorrhagic phase of the acute radiation syndrome due to exposure of the whole body to penetrating ionizing radiation. Am. J. Roentgenol. 67 (1952), 796.

Hooker, D. R.: Physiological effects of air concussion. Amer. J. Physiol. 67 (1924), 219.

Sokoloff, B., Redd, J. B., and Dutcher, R.: Vitamin P protection against radiation. Science 112 (1950), 112.

Zuckerman, S.: Experimental study of blast injuries to the lungs. Lancet 1940: II, p. 219.

— The problem of blast injuries. Proc. Roy. Soc. Med. 34 (1941), 171.

BOOK REVIEWS

TOMOGRAPHIC STUDIES ON THE NORMAL AND INJURED KNEE. By Stig Fagerberg. 93 pp., 51 illus. and 1 table. Acta radiol. Suppl. 138 (1956). Sw. Kr. 30: —.

The work was carried out to assess the value of tomography in the diagnosis of intra-articular fractures of the knee and injuries to the menisci and cruciate ligaments, as well as to establish the indications for its use.

The apparatus used in the present study is of the unidirectional type with two amplitudes of approximately 20° and 40°.

The first part of the work is concerned with definition in tomography. Different conditions of blur inherent in the tomographic method are discussed and, as far as possible, calculated. The importance is stressed of suitable orientation of the object within the layer in focus in relation to the amplitude and the direction of movement of the tube. The visualization of curved surfaces is demonstrated.

The main part of the work consists of a tomographic study of the normal and injured knee. In most experiments and in clinical practice, tomography was performed with the movement of the tube parallel to the longitudinal axis of the limb, using the small amplitude and a distance of 1 cm between the sections.

After brief mention of simultaneous tomography, the suitability of tomography for anatomic studies is stressed. A detailed description is given of the tomographic anatomy of the intra-articular parts of the tibia and femur, based on studies of tomograms of 100 normal knee-joints.

Comparison of tomograms and standard roentgenograms of anatomic specimens with fractures and defects produced experimentally shows the absolute superiority of the tomographic method, especially when the lesion is situated in the tibia, in the intercondylar fossae, or in the anterior and posterior parts of the lateral condylar surface, where cortical defects with a diameter of up to 1.5 cm may otherwise be overlooked. When compression of the spongiosa is present, the chances of the lesion being visualized by standard roentgenography are markedly increased. Fissures are easily missed by both methods, especially if they lie parallel to the longitudinal axis of the bone.

A clinical material of 174 intra-articular fractures comprises: 1) 106 fractures unequivocally visible on conventional roentgenography, but in which tomography provides a better means of judging the degree and extent of the lesion. The greater the abnormality the more superior is tomography. 2) 12 cases in which the conventional frontal and lateral films indicate only the presence of a skeletal lesion, usually by revealing compression of the cancellous bone, but in which the tomograms localize and exactly define the lesion. This group also includes fractures visible in the roentgenograms only after scrutiny of the tomograms. 3) 8 fractures visible only on tomography. These are situated in the posterior or middle part of the lateral condylar surface of the tibia, the depression of the joint surface not exceeding 2 mm and no compression of the spongiosa being present. 4) 33 cases had no signs of fracture on conventional roentgenography and tomography, and the absence of haemarthrosis or the presence of haemarthrosis without fat-drops has been taken as indicating the absence of fracture. 5) 15 cases with no signs of fracture, but with haemarthrosis with fat-drops, were considered to consist of overlooked fractures and injuries of the fat-pad.

The normal menisci were studied in anatomic specimens and in a series of 50 normal cases, the tomo-arthrography, *i. e.* tomography in combination with arthrography, being compared with conventional roentgenography. With the exception of the anterior horn of the medial cartilage, the menisci are correctly visualized by tomography, but regularly

appear less sharply than in conventional films. Recesses and bursae are usually effectively blurred out, but the anterior and posterior capsular attachments of the menisci are difficult to assess owing to residual shadows, sometimes incorrectly interpreted as a loosening from the capsule.

Experiments and studies on a small clinical series of meniscus injuries indicate that the extent of a lesion and the presence of displaced fragments are easier to judge by tomography. Even transverse tears can be demonstrated. On the other hand, owing to increased blur and impaired contrast, the lesions appear less distinctly, and if the contrast medium is dilute they may be overlooked altogether. For that reason there seems to be no indication for the introduction of tomo-arthrography into the routine examination, though the diagnosis may be facilitated in certain cases, such as those of joints with large bursae and recesses or with a complicated structure. A few cases are presented, one of them showing a false diskoid meniscus.

The normal anatomy of the cruciate ligaments is described in detail, together with tomo-arthrography in cases of intact and ruptured ligaments both in anatomic specimens and in a series of patients. The examination was performed only in the lateral projection, with the knee flexed 45 to 90°. The ligaments are visualized distinctly with only minor anatomic variations, and always better than by standard arthrography. Recent and old ruptures of the anterior part of the anterior ligament are always clearly demonstrated. The rare lesions at the tibial attachment of the posterior ligament, however, seem only to be demonstrable indirectly by the presence of an avulsed fragment of bone. Visualization of lesions at the upper attachment of either ligament is impossible unless considerable displacement has taken place or the injury is old and the ligament atrophic.

On the basis of limited experience it seems justifiable to conclude that tomo-arthrography is superior to standard arthrography in assessing normal and ruptured cruciate ligaments.

Finally the value of tomography as a means of widening knowledge of the anatomy of the knee-joint and of facilitating the interpretation of the conventional films is emphasized.

Autoreview.

DIE WIRBELVERSCHIEBUNG IN DER LENDENGEGEND. 2. erweiterte Aufl. Von J. E. W. Brocher. 148 S. 242 Abb. Georg Thieme, Leipzig 1956. DM. 30: 20.

The author reviews our present knowledge of the different forms of displacement of the spinal vertebrae. The treatment is most detailed, illustrated with good reproductions from the author's own material, and accompanied by descriptions of cases and histories.

As a term to be used in spondylolisthesis, the author suggests dysplasia of the arch to indicate olisthesis as well as elongation. With some reservation, he accepts the term pseudo-spondylolisthesis by reason that this term has been widely adopted. It would be more appropriate from the point of view of pathogenetics, according to the author, to reserve the term spondylolisthesis for the genuine displacement occurring in combination with characteristic changes in the spinal arch, and to designate other types of displacements as anti-, retro-, and latero-, respectively.

In this, as in other discussions on displacement of vertebrae, it is in the main the static condition which is taken into account. Due consideration has, in the reviewer's opinion, not been given to the fact that a dislocation between two vertebrae, observed in a certain position of the spinal column, may disappear when the posture is changed. It is evident that such displacement is a functional result of instability in the intervertebral disks.

Folke Knutsson.

PRINCIPLES OF CHEST X-RAY DIAGNOSIS. By George Simon. 173 pp., 162 illus. Butterworth & Co., London 1956. 50 sh.

In the introduction, the author writes: "This book is written for the student radiologist and for the clinician who is particularly concerned with chest diseases, whether he interprets the radiographs himself or has the cooperation of a radiologist." This statement indicates the character of the book; although written by a radiologist it seems to be intended mainly for the clinician.

Fluoroscopy is not dealt with at all. It is taken for granted that the role of the physician begins when he is confronted with a frontal film of the chest, which as far as can be understood, has been produced as a matter of routine by a technician. If then he, the physician, finds something of an obscure nature, he may order further views in lateral or oblique projections to be taken. To a radiologist who is in the habit of using fluoroscopy as a means of gaining a preliminary idea about the actual state of the chest and then proceeding with the examination himself, the author's method appears strange. It even seems to present comical consequences, as for instance when the author with reference to the nipple states that it may be necessary to make a differentiation from intrapulmonary shadows and suggests that "for this the simplest procedure should be chosen which will serve the purpose". Several procedures are proposed, and one of them is "to place a piece of fuse wire around the nipple". Yet, the even more simple procedure of making use of fluoroscopy is not even mentioned.

In his treatment of the subject, the author always starts from the roentgen findings. The first chapter deals with the normal view, and the next with "homogeneous shadows". Under the last-mentioned heading "unilateral total homogeneous opacity, large homogeneous shadows occupying only a part of one side, pleural shadows, lobar consolidation, segmental consolidation ..." are described in turn. Each one of the separate findings is made the object of a diagnostic discussion. All the chapters are built up in the same manner. It is, of course, quite justifiable to commence with the roentgen appearances and from these to assess the anatomic changes that may have caused the deviations from the normal. Yet, it cannot be denied that now and then when reading the book one could have wished for a supplementary discussion with a pathologic process as the starting-point as, for instance, when posing the question in lung cancer: What are the various roentgenologic appearances met with? The book supplies a large amount of knowledge about the normal as well as pathologic conditions of the lungs, but the heart and vessels, on the other hand, are treated but rather briefly and incompletely. It is, for instance, quite wrong in principle as well as from a practical point of view to use a transverse measurement for expressing the size of the heart, an organ which should be measured by volume.

In some of the chapters, bronchography and tomography are described, but angiocardiography is omitted on the grounds that this method belongs to the field of cardiology. If this fact were to imply that the examination should be carried out by a cardiologist, definite protests must be raised. Angiocardiography is a part of roentgen diagnostics and as such should be performed by specially trained radiologists.

The book opens with an extensive section dealing with definitions of terms. The author expresses the hope that it may be possible to agree on the use of identical terms in all international literature although he is doubtful about the chances of reaching this goal. With this concept in view, he considers it the duty of every author to define his own terminology. He does so himself and this makes the book easy to read.

Gunnar Jönsson.